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A NEW SERIES OF SMALL RADIO VALVES

by G. ALMA and F. PRAKKE. 621.396.694-181.4

The development of radio valves having flat bases and of either all-glass construction or with metal envelopes made it possible to reduce the dimensions appreciably, and particularly the overall length, while at the same time maintaining good performance at very high frequencies. The downward trend of dimensions was halted, in the case of metal valves, at the point where further reductions in size resulted in excessive mutual capacitances and dielectric losses between internal leads, and, in the case of all-glass valves, at the point where the proximity of the electrode assembly to the seal between base and envelope exposed the cathode to excessive temperature during the sealing operation. In a new series of valves now developed by Philips, and known as the "A" series or "Rimlock" valves, over-heating of the cathode is avoided by joining bulb to base with a glaze or cement which becomes plastic at a comparatively low temperature. Further substantial reductions in bulb diameter have been achieved. A diameter of 22 mm has been adopted to permit the use of eight contact pins in the base, thus providing the maximum number of connections required in normal receiving valves, and to ensure that there shall be no over-heating of the bulb in the case of valves of the highest dissipation (*i.e.* 14 W for an output pentode). This article describes in some detail the construction and manufacture of these valves.

Over a considerable period the general internal structure and form of envelope (bulb and lead-in wires) had become stabilised, the so-called "pinch" construction being considered normal practice. But certain new requirements in radio engineering called for new developments — developments which would satisfy, for example, the needs of the manufacturers of small, inexpensive sets for which there is a demand in most countries, and the requirements for short-wave and very-short wave reception including television reception.

Small, compact receiving sets call for the production of valves and other components of the smallest possible dimensions, and in this connection the past seven or eight years have seen remarkable developments, the first stages of which have already been the subject of articles in this periodical [1][2]. In the new series of valves about to be described, further reduction in size is once more a prominent feature but, as will be explained, this reduction has been made possible by a new manufacturing technique which has at the same time resulted in improved performance in short-wave operation.

Glass and metal valves with flat bases

In valves which are to be used for short-wave (and, when required, for ultra-short-wave) reception it is essential, amongst other requirements, that capacitances between the leads to the various electrodes, and the dielectric losses in the insulating material between these leads should be very small.

An important advance in this direction was made when the original "pinch" construction was abandoned in favour of a bulb with a flat base [1]. In these valves the lead-in wires were much shorter; they were enclosed in the glass for a short distance only; and they were spaced well apart. These leads could also be made to serve as the contact pins, thus avoiding the necessity of fitting a base cap of plastic material, which has been the source of large and variable losses. Moreover, the short overall length of the leads resulted in proportionally smaller self-induction and opened up new possibilities for the use of valves of this type for very high frequencies (metre waves) [3].

At this stage, the wished-for reduction in valve dimensions and the equally desirable improvement in performance on short-waves were being attained

1) Philips Techn. Rev. 4, 162, 1939.
2) Philips Techn. Rev. 6, 318, 1941.

3) See for example Philips Techn. Rev. 3, 103, 1938.

by one and the same means. But when further development was attempted on the same lines the two requirements came into conflict. Any considerable decrease in size of receiving sets demanded a reduction in the diameter of the valves, since this dimension largely determines the area of the receiver chassis. But reduction of valve diameter involves a closer spacing of contact pins in the flat valve base, and this results in increased mutual capacitances and dielectric losses.

This difficulty was most pronounced in those valves which employed both bulb and flat base made entirely of metal, with the contact pins fused into the base with glass beads, and this construction gave little prospect of further reductions in valve diameter. It had, however, one important advantage over the all-glass construction, in that the sealing of the metal bulb to the base is achieved by only very slight increase of temperature in the electrode system, since the heavy welding machine employed for this operation generates, in a single current impulse of short duration, an accurately calculated amount of heat which is quickly dissipated to the welding electrodes and surrounding material due to the high thermal conductivity of the metal parts. In the all-glass construction, however, bulb and glass base had to be raised to a temperature of some 800 °C to 900 °C, and in proportion as the diameter of the valve and the length of the leads are reduced, the distance between the parts of the electrode system and the seal also becomes smaller, and the temperature to which they are exposed during the sealing operation becomes greater. The smaller the valve, therefore, the greater the risk that, during sealing, parts of the electrode system may be oxidised and that the cathode may have its emission impaired by the chemical action known as "poisoning". Excessive manufacturing rejects can, in these circumstances, be avoided only by passing an inert gas such as nitrogen through the valve during the sealing operation — a manufacturing complication which cannot be contemplated with equanimity.

The "glazing" technique

The problem outlined above has now been solved in the case of all-glass valves by adopting an entirely new method for joining the bulb to the flat base. Instead of direct fusion, a "glaze" or cement is used, the material selected having a melting point much below that of the glass.

When the glass base with its moulded-in contact pins has been made, a moulded ring of the powdered cement is placed round the upper edge of the base. The whole is then raised to the temperature at which the "glaze" melts and becomes firmly bonded to the glass base (see *Fig. 1*), and is then slowly cooled to relieve the mechanical stresses in the glass.

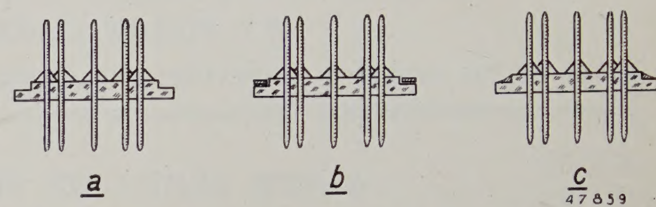


Fig. 1. *a*) Base plate of a radio valve of A series with moulded-in contact pins. Actual size.
b) Same base plate with ring of glaze laid upon it.
c) The ring of glaze is fused on the glass.

The electrodes are then assembled to the supports, the base-plate, complete with electrode assembly, is placed over the inverted bulb in a special sealing machine, and heat is applied until the cement softens, when the base sinks by its own weight far enough to allow the rim of the glass bulb to penetrate the layer of cement. On cooling, the cement sets and adheres to the edge of the bulb to form a vacuum-tight seal (see *Fig. 2*). During the whole of this process it is only the cement and not the glass which is softened, and for the material used in the valves now in production the temperature employed is only some 450 °C. The electrodes, and particularly the cathode, attain a temperature not exceeding 230 °C as compared with 500 °C to 600 °C in the previous method of sealing.

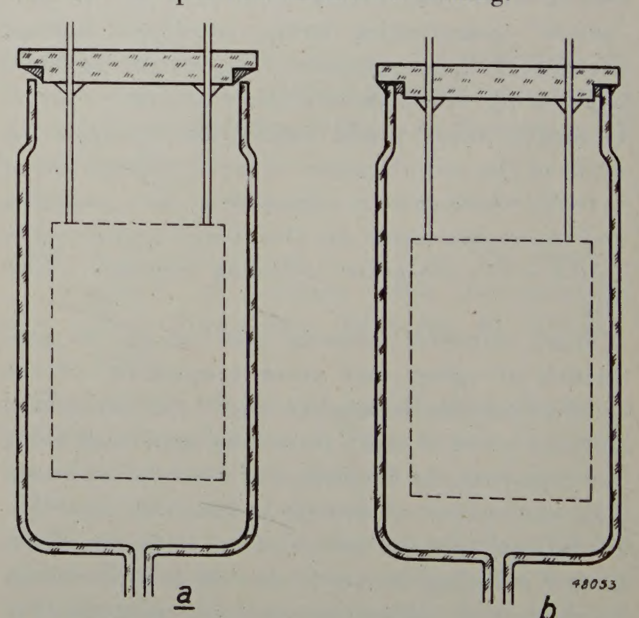


Fig. 2. The joining of bulb and base plate by the glazing technique. 1.5 times actual size.
a) The base plate with the fused ring of glaze is laid loosely on the edge of the bulb.
b) As the glaze melts the edge of the bulb penetrates into the layer of glaze and after the latter has set the bulb and base are securely joined and vacuum-tight.

In order to avoid risk of dangerous mechanical stresses being set up in the valve while cooling after sealing, it has been necessary to find a glaze or cement having a coefficient of thermal expansion practically equal to that of the glass used for the bulb and base. Moreover, the material had to have a suitable surface tension, so that the meniscus of the layer of glaze is slightly concave (see Fig. 1*c*) to prevent the base from becoming displaced to one side when placed on the bulb as shown in Fig.2*a*.

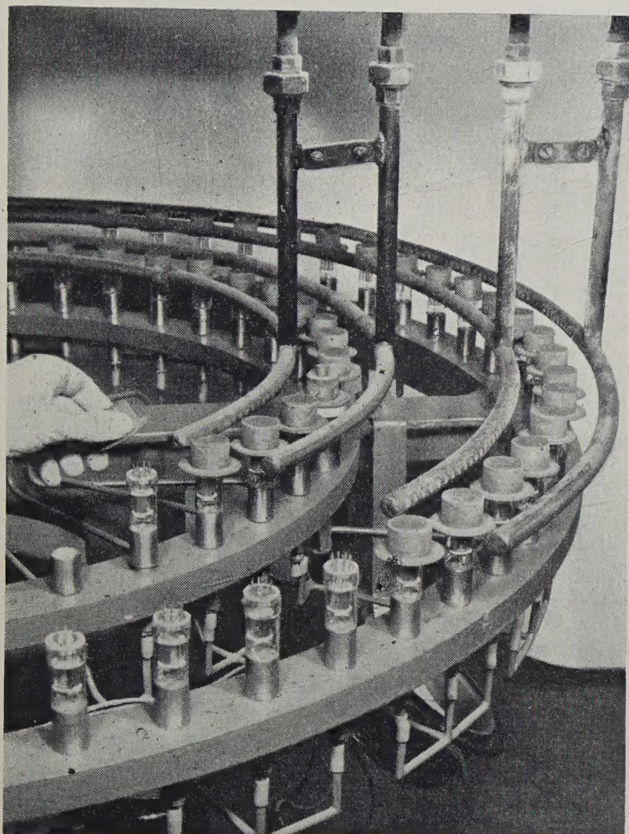


Fig. 3. Detail of the sealing machine on which bulb and base plate are joined. A metal cap is placed on the base plate (left). The whole passes between two rows of gas flames, the layer of glaze being heated to about 450° C, necessary for fusing.

Fig. 3 shows in detail the machine used in sealing the bulb to the base. A metal cap is suspended over the upward-projecting contact pins of the base. The whole passes between two rows of flat flames directed towards the cap. The edge of the bulb and the base are thus heated uniformly, so that no mechanical stresses are set up in the glass. The weight of the cap assists the rim of the bulb to penetrate well into the layer of cement.

This "glazing" technique has made possible the new series of valves known as the "A" series or "Rimlock" valves, having a diameter of only 22 mm. For the sake of comparision it may be mentioned that the "B" series described previously have a diameter of 32 mm., and the "C" series, which included the short-wave push-pull pentode type EFF 50, a diameter of 36 mm [4]).

Some of the types in the "B" and "C" series are not suitable for inclusion in the "A" series for, reasons which are explained later.

Fig. 4a shows a number of valves in the "A" series; Fig. 4*b* a valve in the "A" series compared with valves in the "B" and "C" series; while the reduction in dimensions is best illustrated in *Fig. 5*, where four successive models of two different valve types, namely an I.F. pentode and an output pentode of similar performance, are shown side by side.

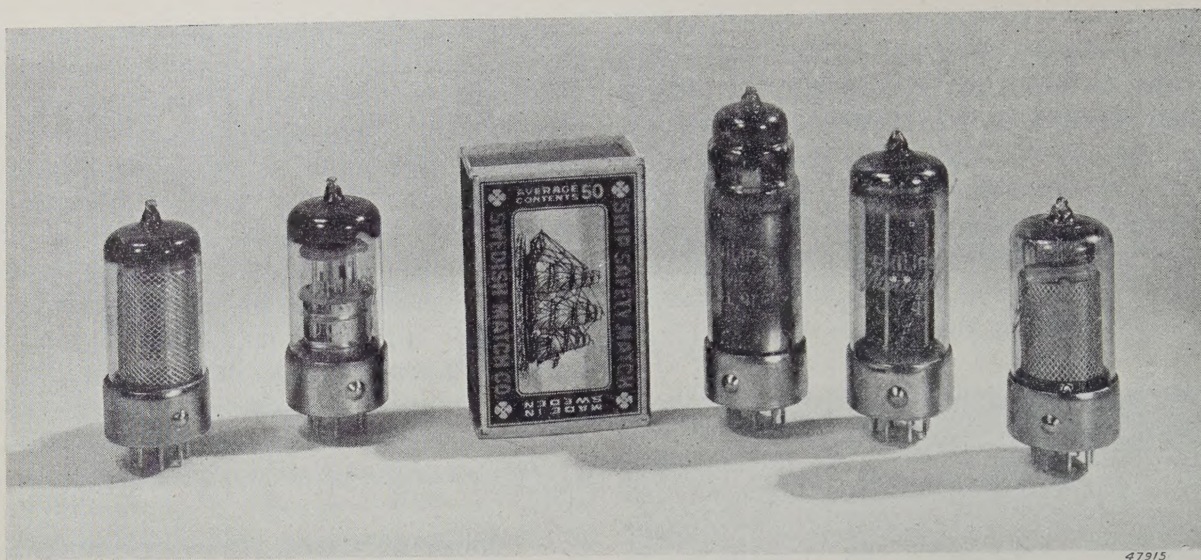
In addition to making possible valves of more compact dimensions, the "glazing" technique confers the general advantage that the bulb can be made to any desired shape, accurate to within 0.1 mm., and that this shape will be maintained during the sealing operation. As examples, *Fig. 6* shows two bulbs without electrode systems. That on the left has a constriction of the envelope close to the base — required for a definite purpose to be explained later. Only by the "glazing" technique can such small details be maintained in the finished product — they would be entirely lost owing to the softening of the glass if exposed to the high temperatures employed in the earlier method of sealing.

A particularly troublesome result of glass softening occurs in small diameter valves, the plastic condition of the glass allowing the contact pins to depart from their vertical alignment, or even to shift their location slightly, with the result that the pins have to be straightened by force. To avoid risk of cracking the glass during this adjustment, the pins must be made of soft metal. This, in turn, introduces the risk that the pins may become bent in service, so that the valve will no longer fit the holder. Using the "glazing" technique, however, the base retains its shape throughout the sealing process, the need for bending the pins disappears, and it is possible to employ pins made of hard metal, not only for the new small diameter "A" series, but also for the valves of larger diameter in the "B" and "C" series.

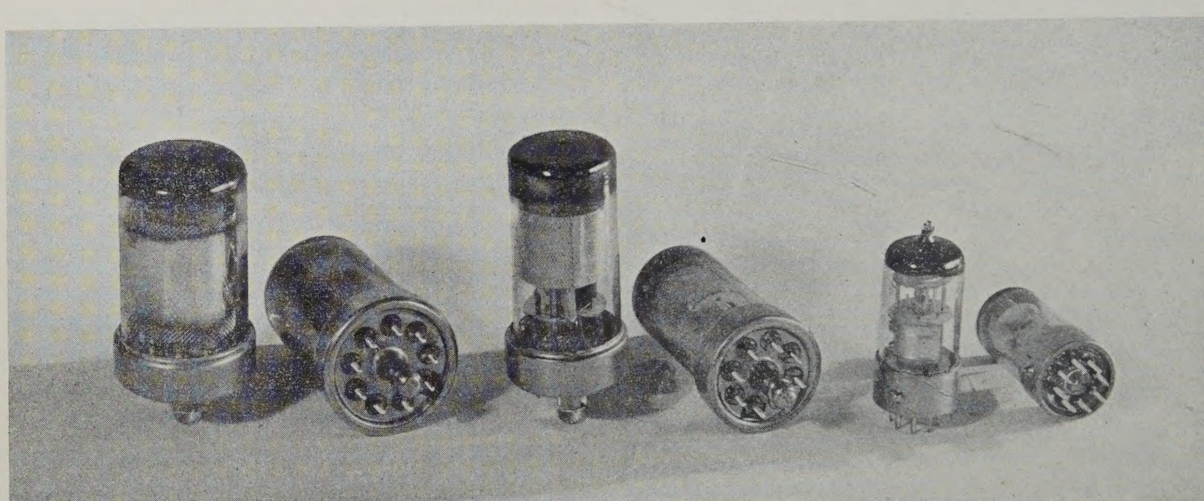
Apart from the practical advantages already indicated, the "glazing" technique results in a simplification of manufacture and a speeding up of production, the latter being due not only to the

[4]) The development of the B and C series, the so-called "key valves", is described in full in the article referred to in footnote [2]).

a)



b)



EFF 50 ECH 21 UCH 41

Fig. 4. *a*) Five valves of the new A series ("Rimlock" valves) diameter 22 mm designed for a normal receiving set. The types shown from left to right are: UCH 41, a triode-hexode; UF 41 an intermediate-frequency pentode; UAF 41, a diode-pentode; UY 41 a rectifier valve and UL 41, a 9 W output pentode. These valves are suitable for A.C. and D.C. sets.

b) For the sake of comparison the following are shown side by side: UCH 41; ECH 21, a triode-heptode which because it requires 9 contacts is made in the previously described B-technique (32 mm diameter); and the short-wave push-pull amplifier valve EFF 50 in the C technique (36 mm diameter).

general simplification, but also to the fact that the lower sealing temperature can be attained more quickly than the higher one.

The new valves

Choice of diameter

Had the cathode temperature during the sealing operation been the sole consideration, a diameter considerably smaller than 22 mm could have been selected. But it is the capacitances and other losses between leads which are now the limiting factors, and the extent to which the diameter can be reduced therefore largely depends upon the number of contact pins it is necessary to set in the base. A further factor is the amount of heat generated in the valve which, in conjunction with the valve diameter, determines the working temperature of the envelope and thus affects to a large degree the dielectric losses and electrolysis of the glass between the pins.

The number of pins required and the amount of heat generated vary widely between valves of different types. Thus, a rectifier valve for a radio receiver needs only four pins, while an indirectly-

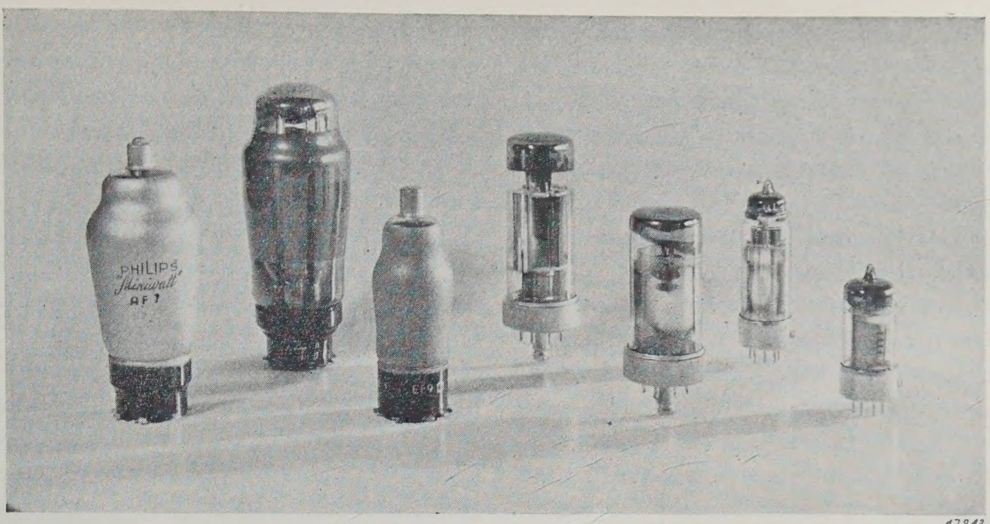


Fig. 5. Successive models, with about the same performance, of an intermediate-frequency pentode (front row) and a 9 W output pentode (back row). Front row, left to right: AF 7 (1937), EF 9 (1937), EF 22 (1941), EF 41 (1946); back row: EBL 21 (1941), EL 41 (1947).

heated frequency changer of the triode-hexode type (which is to be preferred owing to its inherent constancy of tuning on short waves) requires at least eight pins — six for the electrodes (the cathode being common to the triode and hexode sections and two pairs of grids can be interconnected) and two for the cathode heating.

Thus, in principal, different minimum diameters could be selected for each valve type. But this would be very impracticable from the standpoints of both the valve-maker and the set-designer, both of whom desire the greatest possible degree of standardisation of components.

One diameter only has therefore been chosen for the whole of the "A" series — a diameter large enough to accommodate the maximum number of eight pins and one which does not introduce the risk of excessive bulb temperatures being developed at the maximum total dissipation in any valve designed for a normal receiving set — namely the 14 watts dissipated in a 9 W output pentode which, in order to obtain a high mutual conductance, is provided with a long cathode consuming $4^1/_2$ W. The few special valves which require nine contacts are made in the "B" or "C" series.

The diameter of 22 mm. selected for the "A" series provides ample security so far as insulation at high voltage is concerned. It has even been found that a special television valve designed for a peak voltage of 4 000 volts could be operated with that voltage applied between two diametrically opposite pins without risk of electrolysis of the glass or of breakdown. This valve is illustrated in *Fig. 7*.

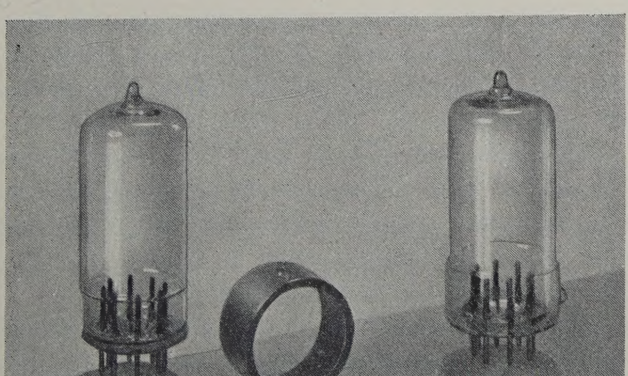


Fig. 6. Photograph of the envelope of the A valves without electrode system. Evacuation and sealing off take place at the top of the valve. The sealed off point is reinforced by moulding it into a compact conical form immediately after sealing off. The two envelopes shown have different forms of guiding mechanism for mounting the valve in the holder (see the final paragraph of this article).

In the U.S.A. very small all-glass valves known as miniature valves with a diameter of 17 mm. have been developed in recent years. These valves, however, have a maximum of seven contact pins. As a consequence, an indirectly-heated frequency changer of the triode-hexode type cannot be made in that series, and only output pentodes of low mutual conductance or small output, unless a high working temperature of the bulb is accepted.

Construction of the electrode system

It is generally desirable to construct the electrode system of a radio valve in such a way that it can be mounted on two or three support rods and that it stands free from the walls of the envelope. This construction is not only simpler than that in which the electrode system is supported from the walls

by rings or discs, but it also reduces the risk of the assembly being distorted while being inserted into the bulb. The free-standing construction is not, however, easy to achieve in bulbs of small diameter owing to the risk of the electrode system striking the walls of the envelope under conditions of mechanical shock or vibration, thus giving rise to noises when the set is in operation.

The selected diameter of 22 mm is, however, sufficiently great to permit free-standing construction to be adopted for most types, including the triode-hexode, pentode and diode-pentode, each of which has a length of 43 mm.

Only for the 9 W output pentode and the rectifier in the new series has it been necessary to support the electrode system from the walls, these valves having comparatively long electrode assemblies and bulb lengths of 61 mm and 52 mm respectively (see Fig. 4*a*).

The multiple valves in the "A" series, such as the triode-hexode and diode-pentode, differ from earlier valves of similar type in that the more complex of the two electrode systems is mounted below the simpler. This simplifies the construction of the support rods and the mica discs employed to give the whole assembly the necessary rigidity. At the same time it confers advantages in connection with the effect of the conduction of heat through the current leads at the bottom of the cathode. A short axial extension of the cathode serves for the simpler system, and the remaining, and longer portion of the cathode for the more complex system. The

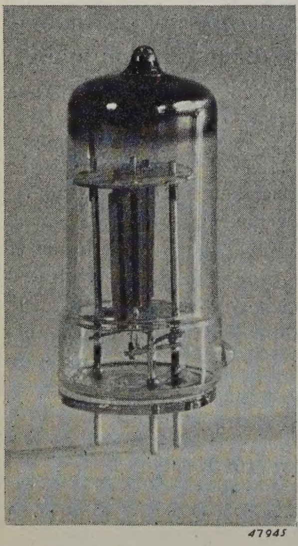


Fig. 7

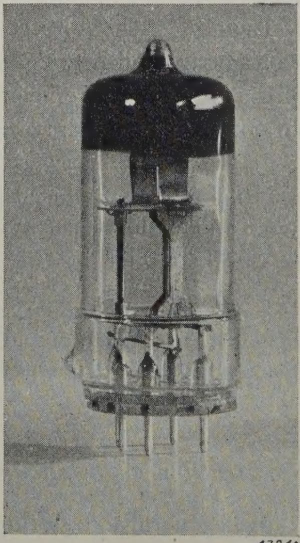


Fig. 8

Fig. 7. Diode for television purposes. The highest voltage that may come to lie between 4 diametrically opposite contact pins amounts to 8000 volts.

Fig. 8. Double diode (mixing diode) for ultra short waves, with glass guiding stud on the bulb.

average temperature of the longer section will obviously be less affected by heat conduction at one end than that of the shorter section.

The "glazing" technique has special advantages in the case of battery valves, in which it is important to keep to a minimum the power required to heat the cathode. A directly heated cathode consisting of the thinnest practicable wire with a very thin coating of a highly emissive oxide is thus indicated [5]). Using the normal nickel filament, wire diameters below 20 microns are not practicable because of the low tensile strength of the material. It was for this reason that for many years Philips have used tungsten filaments which have much higher tensile strength and can therefore be made much thinner. Tungsten wire is, however, more susceptible to oxidation than nickel, and it is in this connection that the low sealing temperature employed in the "glazing" technique confers a great advantage, permitting the use of a filament wire only 8 microns in diameter, for which a heating current of only 12.5 mA is needed.

Valve holders

A radio valve and its holder should be so constructed that when fitting the valve in the holder there is no risk that the pins can enter the wrong sockets.

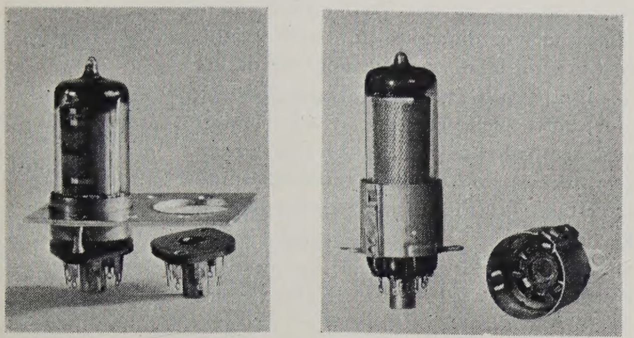
The earliest method of ensuring this was to space the contact pins non-uniformly in the valve base, but it was then difficult to insert the valve correctly into a holder, especially when the latter was located in a more or less inaccessible position in the receiver. Furthermore, in the small all-glass valves where the old sealing technique necessitated the use of soft metal pins there was considerable risk that valves would be forced into the holder, and this introduced the danger of the glass base being cracked.

The method adopted for the "A" series and also for the "B" and "C" series is to space the contact pins uniformly around a pitch circle and to provide some form of locating device to ensure that the valve is inserted in the correct position.

In the "B" and "C" series the locating device consists of a stud at the centre of the base. In the "A" series a metal ring is cemented to the lower portion of the bulb, where the diameter is slightly reduced. This ring carries a small rounded projection or boss which fits into a corresponding groove in the edge of the valve-holder — hence the name

[5]) In these valves the proportionately smaller cathode surface of the thinner wire has practically no effect on the valve characteristic.

"Rimlock". As already explained, the possibility of fitting this ring closely round the bulb within very small dimensional tolerances is entirely due to the low sealing temperatures required by the "glazing" technique.



a) 47943 b) 47944

Fig. 9. *a*) Simple valve holder for the A series. The stud on the rim of the bulb falls in a groove in the edge of the holder. The valves are therefore called "Rimlock" valves.

b) Valve holder with locking device. The valve is held fast by means of a spring which locks over the stud when the valve is inserted. The small can in the middle of the holder provides a screen between the contact pins right up to close under the base plate.

Further, owing to the complete absence of bulb distortion, the metal ring can be dispensed with and the locating boss can be formed on the glass wall itself, as is shown in the empty bulb illustrated in *Fig. 6*. *Fig. 8* shows a double diode (mixing diode) for ultra short-wave operation. This solution is particularly advantageous in ultra short-wave valves as the metal ring would substantially increase the capacitances of the leads.

The locating device described above makes possible great simplification in the design of valve-holders. In *Fig. 9a*, for example, a holder is shown consisting of a flat plate carrying the contacts and suspended by two bolts about 8 mm below the top deck of the chassis. A circular hole in the chassis permits the valve to be inserted, and a notch at the correct point on the circumference of this opening serves to accommodate the locating boss of the valve.

It is often desirable, particularly when a receiver has to be transported with the valves in position, to combine a locking device with the locating arrangement. A holder incorporating a locking device is illustrated in Fig. 9*b*.

In Figs. 9*a* and 9*b* can be seen a small metal can at the centre of the holder. When the valve is in position the can reaches just below the underside of the valve base and serves as an electrostatic screen between the contact pins, especially between the anode and control grid pins. In the "B" and "C" series valves this function was, of course, performed by the central spigot.

THE USE OF ISOTOPES AS TRACERS

by A. H. W. ATEN Jr. and F. A. HEYN.

539.16.08:539.155.2

When a small amount of a suitably chosen radioactive or stable isotope is added to one of the substances taking part in a physical or chemical process, it is possible to follow the atoms of that isotope right through the process, to detect their final resting place and to study their distribution by means of their radioactivity or difference in atomic weight. The isotope thus used as a tracer can be employed to furnish information about the nature and the progress of the process in question. This is especially true for processes in which there is an exchange of identical particles. Since such processes are very important in physiology and chemistry, and the tracer method is at present the only known method of demonstrating and investigating such processes, it has found extensive application in these fields. But also for numerous investigations which in principle could be carried out in other ways, the tracer method is found to be of great value, thanks partly to its extremely high sensitivity and partly to the great ease with which the questions presented can be answered. In this article a series of examples is given illustrating the use of the method.

Introduction

When the periodic system of chemical elements was set up in the course of the previous century, it was thought that each element consisted of only one definite kind of atom. Later this was found to be incorrect: an element may consist of different kinds of atoms which have practically identical chemical properties — the criterion for denoting the atoms by the name of the respective element — but differ in atomic weight by one or more units. Such isotopic atoms, so called because they have to be given the same position in the periodic system, may be stable or unstable. In the latter case they undergo a gradual change, accompanied by a radiation, into another kind of atom; they are then radioactive.

Almost all the kinds of atoms occurring in nature are stable. There are only a few unstable ones, namely the well-known substances with natural radioactivity, such as radium, thorium, uranium etc. In addition to these, however, it is nowadays possible to turn each element into one or more new isotopes which do not occur in nature, all of which are unstable (artificial radioactive substances).

A single example will serve to illustrate the above. The element calcium occurring in nature consists of at least six stable isotopic kinds of atoms, namely for 96.96% Ca^{44}, *i.e.* calcium atoms with an atomic weight of 40 (in round numbers), and further 0.64% Ca^{42}, 0.15% Ca^{43}, 2.06% Ca^{44}, 0.0033% Ca^{46} and 0.19% Ca^{48}. Furthermore, up to the beginning of the year 1944 it had been found possible to make artificially six more radioactive calcium isotopes with atomic weights 39, 39, 41, 45, 49, 49. The various unstable isotopes can further be distinguished from each other by the character of their radioactivity. In the case of a radioactive atom a certain percentage of the atomic nuclei present is transformed per second into another sort by spontaneous disintegration, each disintegrating nucleus emitting, according to its sort, a negative or positive electron or an α-particle (helium-nucleus). This is often accompanied by an electromagnetic radiation (γ-radiation). The intensity of the total radiation of a radioactive preparation at any moment can easily be measured. As the number of non-disintegrated atomic nuclei is continually decreasing, while the chance of disintegration remains constant for each atom and thus also the percentage of nuclei disintegrating per second, the radioactivity observed decreases with time. The velocity of this decrease usually expressed by the "half-value time", *i.e.* the time in which the intensity of the radiation falls to one half, is characteristic for each isotope. The above-mentioned six radioactive calcium isotopes have half-value times of 4.05 minutes, 1.06 seconds, 8.5 days, 150 days, 2.5 hours and 30 minutes respectively.

The existence of the isotopes is not merely of theoretical interest. In the last 10 to 20 years isotopes have become an extremely useful practical aid for all kinds of scientific and technical investigations. This use of isotopes is based for a large part on the fact that an isolated isotope of an element takes part in chemical and physical processes in exactly the same way as the familiar mixture of isotopes of that element which occurs in nature, while the isotope in question can always be recognized by the investigator and can be traced even in a chemically identical environment, thanks to its radioactivity or difference in atomic weight. The isotope thus functions as a tracer, capable of furnishing information about the process taking place,

which would be much more difficult or even quite impossible to obtain in any other way.

We shall explain this in more detail, but for better orientation of the reader we shall first discuss four examples out of the large number of investigations which have already been carried out with isotopes as tracers.

What can be done with (radioactive) isotopic tracers

First example

In the production of steel, among other substances the phosphorus, which is present in quite considerable quantities in the crude iron, has to be rendered harmless by adding a slag-forming substance or by lining the crucible with a material that reacts with phosphorus. A continuous check has then to be kept of the amount of phosphorus still present in the molten metal. This can, of course, be done by chemical analysis of samples, but results are obtained much more quickly and easily when a small amount of radioactive phosphorus is added to the melt at the beginning of the process. This is rapidly distributed uniformly throughout the melt, so that the ratio between the natural phosphorus present and the radioactive phosphorus added is the same everywhere. If phosphorus disappears from the melt into the slag floating on the surface or into the lining of the crucible this takes place to an equal degree with the natural and with the radioactive element. The decrease in the percentage of phosphorus in the melt can thus be determined merely by ascertaining the decrease in the radioactive phosphorus. This is extremely simple, since it is only necessary to measure the radioactivity of a sample of the melt, which can be done very easily with an electrometer or an electron-counter [1]).

Second example

In many factories the workers come into contact with mercury, and it is known how harmful the regular inhalation of mercury vapour can be; in course of time a concentration of more than 10^{-4} gram of mercury per m³ of air already becomes injurious to health. It is a difficult problem to detect the presence of mercury in such minute proportions, because chemical analyses are unavailing in such cases. In a certain case which occurred in the manufacture of tubular luminescent lamps in an American factory, where the lamps were filled with mercury vapour at a low pressure, a glass side-tube containing a small drop of mercury had to be "blown" onto the lamp, and inevitably the glassblower inhaled a very small quantity of mercury vapour into his lungs. In order to determine how much was inhaled a number of tests were carried out with a volume of 2 liters of air that had been in contact with the drops of mercury under exactly the same conditions as in the manufacturing process, this being drawn off by suction and passed over a metal plate kept at the temperature of liquid air. Practically all the mercury in the air condensed on the plate.

The mercury used for the experiments contained a known, small percentage of a radioactive mercury isotope. The radioactivity of the plate, which was quite simple to measure after the experiment, gave an indication of the amount of mercury contained in the air which had passed over the plate. In this way a concentration of 5×10^{-6} g/m³ could be detected. Average mercury concentrations were found of about 10^{-5} and in one case about 4×10^{-5} g/m³, from which it was concluded that in the manufacturing process in question the glassblower ran no danger of poisoning [2]).

Third example

When a piece of metal is fused with a radioactive lead isotope in an atmosphere of hydrogen and then allowed to crystallize again, there are two possibilities. In some metals, such as thallium and magnesium, lead is soluble to a considerable percentage, the lead atoms being uniformly distributed in the grains and the polychristalline metal obtained. In other metals, on the other hand, such as bismuth, tin, antimony, silver, gold, copper and nickel, in

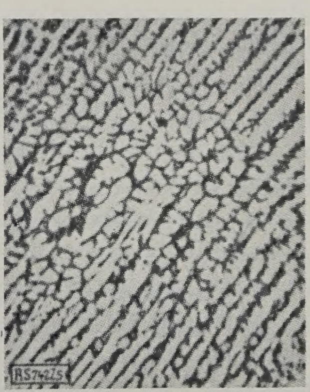


Fig. 1. Radiogram of tin with a radioactive lead isotope (thorium B) deposited at the grain boundaries of the polycrystalline metal. Magnified about six times (from G. Tammann and G. Bandel, Z. Metallk. 25, 154, 1933).

[1]) An electron counter was described *e.g.* by A. Bouwers and F. A. Heyn, in Philips Techn. Rev. 6, 75, 1941. In the measurements allowance must of course be made for the natural decline in radioactivity with time. We shall return to such practical details on a later occasion.

[2]) J. W. Irvine and C. Goodman, J. appl. Phys 14, 496, 1943.

which lead is practically insoluble, the radioactive lead is situated on the boundaries of the grains. When a microscopic preparation of the metal is made and laid on a photographic plate for several hours after development, the plate will be found to be blackened at those places where it lay against radioactive particles, thus where lead has been deposited. By means of such an "auto-radiogram", of which *fig. 1* is an illustration, it is possible in the first place to ascertain whether and to what degree the added lead is soluble in the metal; if the lead is entirely dissolved the entire surface of the photographic plate is uniformly blackened; if the lead does not dissolve, or only partially, the radiogram shows up very nicely also the boundaries of the grains (fig. 1). Thus the isotopic method can also in this case furnish valuable information about the changes taking place in the structure of the metal upon recrystallization and in rolling [3]).

Fourth example

Friction between two metal surfaces is due partly to adhesion, the result being that when the surfaces slide over each other extremely small particles of metal are torn out of one and taken up in the other. This exchange of metal may take place to such an extent that two surfaces become, as it were, welded together (the familiar seizing). The quantity of material thus transferred from one metal to the other is a measure of the contribution of this effect to the total force of friction. In general it is a question of very small amounts which chemically can hardly be detected at all. An investigation has now been carried out with the help of a radioactive tracer [4]). One metal surface was "activated", *i.e.* it consisted for a small part of atoms of a radioactive isotope of the metal. After this surface had been made to slide over the second, non-activated metal surface, the latter also showed a certain amount of radioactivity. Amounts of 10^{-10} gram of transferred metal were detected in this way, and, what is more, by means of a radiogram as described in the preceding example also the distribution of the transferred material on the surface could be studied. From the radiogram shown in *fig. 2a* it may be concluded for example, that in this experiment the sliding of the two metal surfaces over each other was not continuous but took place in small jerks. By this method the influence of all kinds of factors, such as the pressure, the hardness of the surface, etc. on the transfer of material can be studied, as also the effect of a lubricant; see fig. 2*b*.

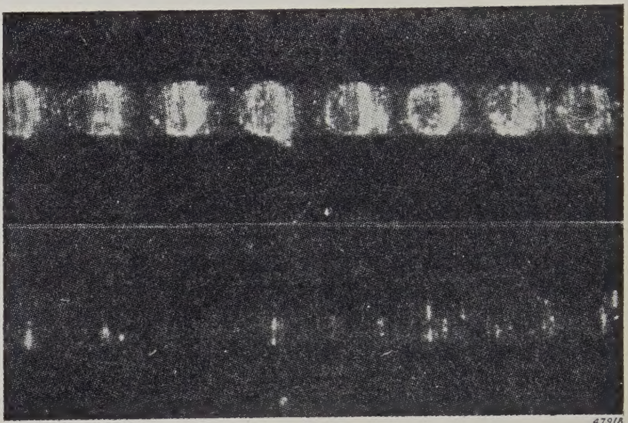


Fig. 2. Radiograms of a metal surface after it has been rubbed with a piece of metal containing a radioactive component. The radioactivity of the surface shows there has been a transfer of material. This explains to a large extent the friction set up when one surface slides over another. The illustration relates to the friction of lead on steel *a*) with no lubricant, *b*) with lubricant. Magnification about six times. (From J. N. Gregory, Nature (London) **157**, 444, 1946).

Why the tracer method is so important

From these few examples we can already deduce the most important aspects which have lent such great significance to the tracer method.

We first call attention to the last example discussed. The transfer of material can also be measured when the two surfaces sliding over each other contain the same metals or even when they are exactly identical. It must be realized that this would not be possible by any other known method, since the transfer takes place in both directions: there is an exchange of identical particles. It would not be possible by any chemical or physical method to ascertain the origin of the metal present on one of the surfaces after the experiment, whereas the radioactive isotope immediately gives the answer.

Processes in which there is an exchange of identical particles are very common in nature, not only in chemistry and metallurgy, but especially in the physiology of plants and animals. The tracer method, which offers the only method of approach, has been used on a large scale for the investigation of such processes, and the publications in that field are innumerable. In a survey of such investigations for the year 1940 [5]) in physiology alone more than 300 publications are cited. But also in the field of technology, for routine tests, and like-

[3]) G. Tammann and G. Bandel, Z. Metallk. **25**, 153 and 207, 1933.

[4]) B. W. Sakmann, J. T. Burwell and J. W. Irvine, J. Appl. Phys **15**, 495, 1944; J. N. Gregory, Nature (London), **157**, 444, 1946 (6 April).

[5]) J. R. Loofbourow, Rev. Mod. Phys **12**, 267, 1940.

wise in agriculture and chemistry, the method is being more and more widely applied [6]).

Although the last example discussed illustrates the possibility of studying the exchange of identical particles with the help of an isotope, the employment of the tracer method in that case is not motivated only by the possibility mentioned. When two different metals slide over each other the transfer of material could in principle be studied also by other methods. The fact that a radioactive tracer is, nevertheless, used, is due to the fact that a much greater sensitivity can be attained with the radioactivity measurements, *i.e.* much smaller amounts of a substance can be detected than with other methods so far available. The same applies to the case of the determination of mercury. In the determination of phosphorus which was discussed as the first example, the indicator method is not necessary in principle either, but it was applied there because of the greater ease with which the quantity of phosphorus could be determined, compared with a chemical or other analysis. Finally, an important point in the employment of a radioactive isotope is that it can be localized so easily when mixed with a different or a chemically identical substance, while also its distribution can be determined; see the radiograms of figs. 1 and 2.

Where radioactive isotopes are applied for the sake of the advantages of greater sensitivity and easier working, while in principle other methods would also provide an answer to the questions raised, one might speak of "untrue" applications of the indicator method. In such cases the nature of the isotope is sometimes a matter of indifference; in order to obtain a radiogram of the grain boundaries in a polycrystalline material it would also be possible to use a radioactive isotope of some metal other than lead, provided it does not dissolve in the base metal. In the "true" applications of the tracer method it is quite different, for there it is essential that an isotope can be detected in identical surroundings.

In this connection attention should be called to the fact that the tracer method can also be applied with non-radioactive isotopes. The atoms of such isotopes are recognizable (labelled) by their different atomic weight and the properties connected therewith, such as specific weight, velocity of diffusion, heat conductivity, etc. The most important atoms to be considered are "heavy hydrogen" (deuterium) of atomic weight 2 (approx.), the oxygen isotope of atomic weight 18 and the nitrogen isotope of atomic weight 15. With such stable isotopes the measurement of the radioactivity of mixtures of isotopes is replaced by measurements of density or the like.

These measurements are generally much less easy than the measurement of radioactivity and also not so sensitive by far. With stable isotopes there is, therefore, no question of "untrue" applications of the tracer method. The reason for using these is solely the possibility of studying processes of exchange, where no suitable radioactive isotopes can be found.

Owing to the very large number of applications of the indicator method (true and untrue) it has become impossible, as well as purposeless, to give a survey of these applications, even if one confined oneself to a definite field. We shall not, therefore, attempt to do so, but in the following we shall say something about the origin of the method and follow this up with a number of suitably chosen examples, with the intention of showing the possibilities of the method from different angles. In a subsequent article we shall go more deeply into the practical performance of investigations with radioactive and also with stable isotopes. As to this practical performance we can only point out here that it is not necessary to prepare the radioactive (or stable) isotopes oneself, for they can be obtained from certain suitably equipped laboratories. In Europe the Philips Laboratory in Eindhoven, among others, has already supplied suitable radioactive substances for a number of applications.

Origin of the method

The tracer method was initiated by Hevesy, who first discovered the possibility of studying processes of exchange by that means and immediately put his ideas into practice (in 1915). He used the method, for instance, to test the theory of Arrhenius about the dissociation of electrolytes. In essence his experiment was as follows. From a certain amount of normal lead a lead salt is prepared, for instance lead chloride, and from a corresponding amount of the radioactive lead isotope, which is formed as a disintegration product of radium, another salt, for instance lead nitrate is prepared. When the two salts are dissolved in water, the solutions mixed, and then the two salts extracted separately from the mixture, the two lead compounds are found to have become equally radioactive.

The lead atoms from the two salts must, therefore,

[6]) See, for example, the survey of chemical applications by G. Seaborg, Chem. Rev. 27, 199, 1940, where more than 500 publications are mentioned, most of them different from those in the article by Loofbourow.

have been completely mixed in the solution. This result agrees entirely with the hypothesis that the lead compounds are dissociated in the solution, *i.e.* that lead occurs therein in the form of free ions.

We have just said that one salt was prepared from normal lead and the other from the radioactive lead isotope. Consequently, in order to carry out the experiment in this way a sample of the pure radioactive lead isotope would have to be available. Actually, however, this is not necessary. It is sufficient if one sample of lead contains only a small amount of the radioactive isotope. Hevesy recognized this from the very beginning, as may be seen from the curious story of the way in which he came to use the isotopes in this way. He had tried in vain to separate radium *D* from a quantity of lead containing a small amount of that substance. Since radium *D* is an isotope of lead (the radioactive isotope mentioned in the radium series; its name dates from the time when there was no clear idea of the situation), it cannot, as we now know, be separated by ordinary chemical means. It was just this failure that gave Hevesy the idea that he could always distinguish the lead of this sample "contaminated" with radium *D*, from a sample of ordinary lead: in all mixtures with ordinary lead every fraction of the "contaminated" (radioactive) lead sample takes an equal fraction of the original radioactivity with it and can thus be determined quantitatively by measurement of the radioactivity.

The "contaminated" lead is thus, as it were, indicated or labelled by the radioactive isotope itself, and provided it is a homogeneous mixture the whole sample can serve as a quantity of labelled atoms. This is in fact obvious when it is borne in mind that the radioactivity of an element only means that per unit of time a certain percentage of the atoms present in a sample disintegrates spontaneously. If the sample also contains a number of isotopic atoms which are stable and thus will never disintegrate, the only result, in the first instance, is that the percentage of disintegrating atoms per unit of time, is smaller, thus the radioactivity is "diluted". In fact, also in the first examples discussed there were certain dilutions of radioactive phosphorus and mercury, and this is usually the case with artificial radioactive substances where the degree of "concentration" of the radioactivity depends upon the preparation of the substance. We shall return to this in a subsequent article.

Hevesy's applications of radioactive substances were not confined to exchange experiments. He realised also the significance of radioactivity measurements as a substitute for chemical analyses, owing to the great ease and sensitivity of the method as illustrated by our first examples, and he thus also made use of "untrue" applications of indicators. Once, when he had reason to suspect the cleanliness of his landlady, he smeared a bit of "dirt" with a radioactive substance on his dinner plate and checked daily whether the plate had been properly washed simply by measuring the radioactivity which (literally) still clung to it. He was indeed able to detect radioactivity of the plate for many days. Whether or not this was to be ascribed to the carelessness of the landlady or to the extreme sensitivity of the method, history fails to relate.

Denomination of the method

Hevesy called a radioactive isotope used for the experiments described, an indicator, and thus following his example one often speaks of the indicator method. In recent years in English-speaking countries the terms "tracer method" and "tracer atoms" have become more usual: the radioactive isotopes are used, as it were, for discovering and following a trace. "Labelled" and "tagged" atoms are also often spoken of. The terms speak for themselves. Finally, to complete the list, we may mention the denoting of these atoms as "spies", as proposed by Evans [7]). This name is meant to indicate that each atom of a radioactive isotope can move about unrecognized in a "crowd" of even similar atoms until at a certain moment it "betrays" its presence and whereabouts by its disintegration. The concentration of "spies" in the experiments usually lies between 1 to 10^{10} and 1 to 10^{15} normal individuals. Translated into terms of human society, this would be equivalent to one spy among a population at least five times as large as that of the whole earth.

Further examples of the application of tracers

The examples which will be discussed in the following in unrelated order, will give the reader an idea of the multifarious nature of the applications of indicators. In order to reduce them to some kind of systematic order we have sorted out the examples into three groups according to the character of the problem. In the first group the problem is only where something is situated (localisation), in the second group how much of a substance there is, remains over or takes part in a process (quantitative problems); in the third group it is particularly a question of exchange processes. It must be said, however, that often the boundaries between the groups cannot be sharply drawn. In localisation problems one is obviously always concerned with "untrue" indicator applications, as is also usually

[7]) R. D. Evans, Applied Nuclear Physics, J. Appl. Phys **12**, 260, 1941.

the case in the second group (quantitative problems), while the last group contains only "true" cases.

Localisation

A very old example is the tracing of samples of radium that have been lost in hospitals through carelessness or theft; the places where the sample might possibly be, for instance the refuse heap, are gone over with an electron counter. A more modern case is the tracing of stoppages in an oil pipeline. In the periodical cleaning of the walls of the pipe a screw-shaped scraper is placed in the line and pushed along by the pressure of the oil itself. If the scraper gets jammed somewhere, it has to be located as quickly as possible, in order to open the line at that point and remove the accumulated deposit. With the help of a radioactive indicator this localisation is astonishingly simple. A scraper is used that contains a little radioactive material emitting γ-radiation, which easily penetrates through the walls of the pipe and can be detected with a somewhat modified "electron counter". One rides along the line with this "counting" apparatus. until the radioactivity betrays the position where the scraper has stopped.

There is another similar application in the petroleum industry, for determining the setting depth of the cement that is pumped in behind the casing of an oil well. A radioactive mineral, carnotite, is mixed with the cement and when a counting instrument is lowered into the drill hole it indicates a strong radiation at the level of the cement.

Extremely fine cracks in metal surfaces can be detected and localised by applying a greasy paste containing a radioactive substance to the surface of the metal under high pressure. Upon the surface being cleaned, the radioactive paste is left in the cracks, and by making an auto-radiogram of the surface the cracks can then easily be seen.

Quantitative problems

In order to determine the efficiency of a fog, smoke or dust filter, it is necessary to measure the very small quantities of fog-forming or other substances retained by the filter. As fog-forming substance tricresyl phosphate containing radioactive phosphorus is used. When this is passed successively through several filters, their efficiency can be judged by comparing the intensity of their radioactivity.

Radioactive isotopes are sometimes an excellent means of measuring very small solubilities or very low vapour pressures. The vapour pressure of thorium acetyl acetonate, for example, has been determined by preparing a sample of the compound with a strongly radioactive thorium isotope, saturating a given volume of nitrogen with the vapour of the compound and passing the gas through acidified alcohol, in which the compound is absorbed. The thorium concentration can then be calculated from the radioactivity of the liquid and from that the amount of vapour in the given volume of nitrogen.

In general it may be said that radioactive isotopes render valuable service in microchemistry, *i.e.* the chemical investigation of extremely small quantities of a substance, as for instance in adsorption phenomena, in very dilute solutions, etc. Another interesting fact is that radioactivity has made possible the investigation of the chemical properties of the elements "43" and "85" and of several "trans-uraniums". elements which could not be found in nature but from which radioactive isotopes could be prepared artificially in imponderably small quantities.

Important perspectives are opened by the application of radioactive indicators in chemical analysis, so often constituting daily routine work in technology. One example out of many is the following: it is desired to determine the bromine content in a mixture of a bromide and a chloride. A complete separation of the two compounds is very difficult and takes up a great deal of time. If, however, a little radioactive bromine (in the form of the compound in question) is added to the mixture, only a partial separation of the bromine is sufficient. Due to the homogeneous mixing it is known that the ratio between the bromine separated and the total amount of bromine is equal to the ratio between the radioactivity separated out and the original radioactivity. Since the latter ratio is easily determined, it is possible to calculate the desired total content of bromine directly from the amount of bromine separated out.

An application in biology somewhat resembling the above is the determination of the total amount of blood in an animal. After a certain amount of blood has been taken death inevitably sets in and it is then impossible to draw off the rest of the blood. If, however, a solution of some substance or other containing a known quantity of radioactive atoms, is injected into the test animal intravenously and given time to distribute itself homogeneously throughout the whole circulatory system, a small sample of the blood suffices, for the total amount of blood can then be calculated from the percentage of injected radioactive atoms

recovered in the sample. (Of course no appreciable part of the injected substance must have been transferred from the blood to other parts of the body.)

The fact that it is practically unnecessary to interfere with the normal life of the test animal is of importance for many investigations, especially those of a pharmacodynamic nature. We may mention here an investigation into the rate of absorption of insuline which is injected periodically under the skin of sufferers from diabetes. It is often desirable to restrict the number of injections and it is therefore favourable if the insuline is retained for a relatively long time near the point of injection, or stored there as it were, and only slowly taken up in the circulation. By building a radioactive atom (radioactive iodine) into the molecule of three kinds of insuline, *viz.* "ordinary" insuline, globine insuline and protamine-zinc-insuline, and measuring from time to time the decrease of radioactivity at the point of injection, it has been possible to determine that the rate of absorption of the three kinds of insuline in the body decreases in the order given above.

Exchange processes

Although also in chemistry and technology numerous processes play a part where an exchange of identical particles occurs — we mention only auto diffusion, *e.g.* the diffusion of lead atoms in lead — physiology is the most prominent field for such exchanges. One of the most striking examples is the continuous exchange of the building materials of the body. This has been studied in detail with phosphorus in the form of various compounds, with the help of radioactive phosphorus, which lends itself so well for such experiments. Hevesy has particularly done a great deal in these investigations. It has been established that phosphorus does not remain permanently bound in any constituent of the body. The exchange takes place most rapidly between the blood and various organs: of the phosphate ions present in the blood at a given moment after two hours, only 2% are still present, the rest having been exchanged. In the liver and kidneys, too, there is a rapid renewal, but also in the bones and even in the brain the phosphorus is in course of time renewed, though at a much slower rate. The parts of the body that take least part in the continual exchange are the teeth: after 250 days only 1% of the phosphorus in the dental enamel is renewed.

In a certain case it is not so much a matter of exchange as one of selective assimilation of substances by certain constituents of the body, namely where the exchange leads, as it were, to a credit balance for that part of the body. A striking example is the assimilation of iodine by the thyroid gland. With the help of a radioactive iodine isotope it has been determined that, out of an extra amount of iodine administered in the food, after 1 or 2 days a healthy person has stored up in the thyroid gland about 3%, whereas a sufferer from goitre stores up 30% or more; see *fig. 3.* In certain cases of cancer

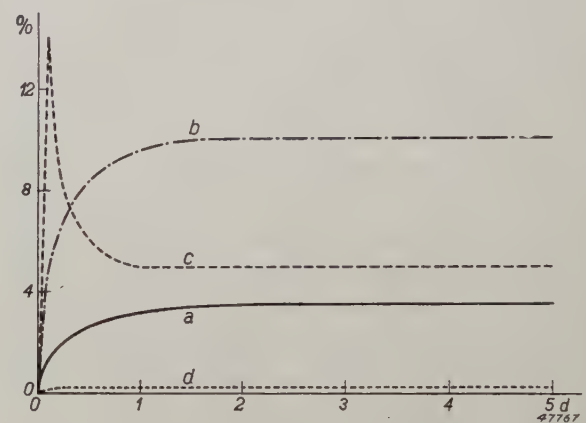


Fig. 3. The assimilation of iodine in the thyroid gland. Along the abscissa is the number of days which has elapsed after the administration of a known extra amount of iodine in food, along the ordinate the percentage of this amount found in the thyroid gland as measured by means of radioactive iodine;
a) for healthy persons,
b) with benign goitre,
c) with Basedow's disease,
d) upon defective functioning of the thyroid gland (myxoedema). (From J. G. Hamilton, Application of radioactive tracers to biology and medicine, J. appl. Phys, **12**, 440-460, 1941).

of the thyroid gland the radioactive iodine was found to be accumulated not in the cancer tissue but in the healthy tissue. (Thus we again arrive at the problems referred to under "localisation".) Somewhat similar phenomena are found in the case of the assimilation of radioactive strontium in the blood and in the bones. It has been possible not only to determine how this process is retarded, for instance, by rockets and then promoted by the administration of vitamin D, and how it is even led in the opposite direction by Basedow's disease, but it has also been possible to study the finer distribution of the strontium assimilated: the strontium was found to accumulate in the hard bone tissue, and in the case of bone cancer it showed a preference for the cancer tissue and possible metastases thereof. Though straying from our subject, it should be pointed out that this last case may be of value to the doctor not only diagnostically but also therapeutically. Given a sufficiently high concen-

tration the radiation of a radioactive kind of atom has a destructive effect on the cancer tissue. If the radiating substance is selectively attracted by the cancer cells, as strontium by bone cancer, this may eventually serve as the basis of a very effective therapeutic treatment. (On the other hand, for physiological applications of radioactive isotopes as indicators it is a general rule that the destructive effect of the radiation must be avoided by keeping the concentrations of the radioactive isotopes sufficiently small. We shall return to this in the following article.)

We shall leave it at these examples. They are sufficient to give the reader an impression of what can be achieved with the tracer method in research work and routine investigation, a method for which uses are to be found in ever-increasing numbers and in even wider fields.

PENETRATION AND WELDING SPEED IN CONTACT ARC-WELDING

by P. C. van der WILLIGEN.

621.791.753.41

In a previous article a description was given of what contact arc-welding is, how the particular electrodes are made and what can be done by that method of welding. Here we will deal with several important advantages, both in welding technique and economy, which are obtained with the new type of electrodes. The shape of the penetration differs from the usual shape in that it is deeper in the middle and shallower at the sides, thus giving a favourable root penetration and avoiding undercut. Furthermore the welding speed, *i.e.* the amount of metal deposited per second, is greater.

Recently a new method of welding was described [1][2], so-called "contact arc welding", in which the electrodes can be kept resting on the workpiece from beginning to end, while the coating of the electrode is in continuous electrical contact with the workpiece. This new method was the outcome of an investigation carried out with the object, *i.a.*, of making touch-welding easier and of more universal application. With "contact electrodes" touch-welding can indeed be carried out easily without fear of the troublesome "freezing". This is due to the fact that the coating of the electrodes is made very thick by transferring a considerable part of the metal from the core wire to the coating. At the same time this makes the coating slightly conductive and this conductivity can be regulated in such a way that the electrode becomes "self-starting". This does away with the necessity of striking the arc by tapping and prevents extinction when welding with alternating current.

The goal which had been set at the beginning of the investigation was thereby achieved. In research work, however, it often happens that after attaining a given goal the conclusion is also reached that the solution found involves certain drawbacks preventing its application. In the development of contact arc-welding the reverse was true. In this case a number of further advantages appeared, while incidental disadvantages were found to be of little importance and easy to avoid. This will be illustrated by reference to the history of the electrode Contact 15. The facts, however, hold qualitatively for all types of contact-electrodes. Besides the electrode Contact 15, two other types were developed: Contact 18 and Contact 20, which were found in practice to be no less important than the first mentioned type. We shall first give a brief resumé of some of the characteristics of the three types of contact electrodes [3]).

The different types of contact electrodes

The contact electrodes Contact 15, 18 and 20 were developed from the ordinary electrodes Ph. 55, 48 and 50, respectively, which, as will be known, differ mainly in the composition of the coating. The properties and field of application of the different types of contact electrodes are thus determined for a large part by those of the corresponding ordinary electrodes. In addition, of course, there are the specific properties connected with the new method of welding.

Thus, for example, Contact 15 and Ph. 55 have in common the high impact value [4]) and the insensibility to sulphur in the material to be welded [5]). Contact arc-welding can be carried out with Contact 15 in all positions except the vertical, where the free arc must be used [6]).

An electrode, the Contact 18, was therefore specially developed for vertical-down contact arc-welding. As basis the electrode Ph. 48 was taken, because this type is particularly well suited for vertical-down welding. Contact 18 can also be used quite well in other positions. Moreover, it gives unusually good results in under-water welding, the advantages of contact arc-welding, namely touch-welding and self-starting, being particularly valuable because under water the welder can see but very little, especially while actually welding, owing to the water around the arc becoming turbid. Contact 20 is an electrode which was developed exclusively for down-hand contact arc-welding. It is known

[1]) Philips Techn. Rev. **8**, 161, 1946.
[2]) The Welding Journal, **25**, 313-5, 1946.

[3]) Contact 15 and Contact 18 have already been discussed in the article referred to in footnote [1]).
[4]) See Philips Techn. Rev. **6**, 97, 1941.
[5]) See Philips Techn. Rev. **7**, 91, 1942.
[6]) The reason for this is explained on page 166 of the article referred to in footnote [1]).

that the welding speed, *i.e.* the amount of metal deposited per unit of time, of the type Ph. 50, which as already stated served as basis, is especially high. Since the higher welding speed, as we shall see, is characteristic of all types of contact electrodes, it will be clear that Contact 20 has an exceptionally high speed, since it was developed from the already fast type Ph. 50. This, in fact, constitutes the most important characteristic of the most recent of the different types of contact electrodes.

Shape of the penetration

A question which deserves particular attention in welding is the shape of the penetration. By this is meant that part of the workpiece that is fused during the welding. When a bead is welded on a flat plate the penetration resembles a segment of a circle, as shown diagrammatically in *fig. 1a* for an ordinary coated electrode.

In the first test with the heavy contact electrodes, however, it was already found that the shape of the penetration differed considerably from the normal, the penetration being deeper in the middle and shallower at the sides, *cf.* fig. 1*b*. This different shape of the penetration is characteristic of all contact electrodes.

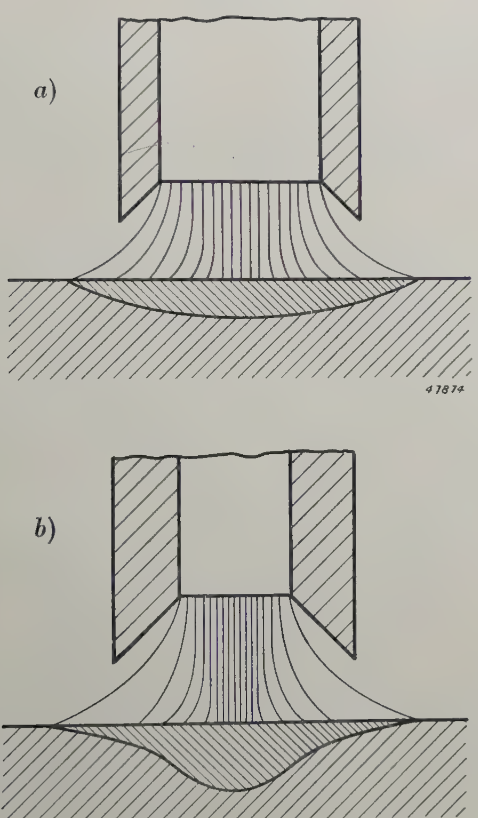


Fig. 1. The shape of the penetration: *a*) in the case of an ordinary electrode and *b*) in that of a contact electrode. The penetration is represented by the heavily shaded parts of the figure (for the sake of simplicity the bead is not drawn). It is also shown diagrammatically that the arc is more concentrated with contact electrodes than with ordinary ones, resulting in the difference in the shape of the penetration.

The explanation of this particular shape of the penetration is not difficult to find, considering that the arc burns only on the core wire; since in contact electrodes the core wire has only a relatively small surface, the arc is more concentrated than in the case of ordinary electrodes where the core wire has a relatively large surface (see figs. 1*a* and *b*). The spraying action of the welding arc, which is the result of the forces acting on the molten droplets [7]) and which, for example, makes overhead welding possible, will therefore, in the case of contact electrodes, also be more concentrated in the centre. Moreover, the longer cup of the contact electrode keeps the droplet better directed, resulting in less spatter. Furthermore, the great depth of penetration in the middle is undoubtedly due to the arc voltages of the thicker contact electrode being appreciably higher than those of the corresponding ordinary coated electrodes, containing the same amount of metal.

It is a known fact that electrodes having a high arc voltage give a deep penetration (such as the "high organic" type in the U.S.A.).

The relatively shallow penetration at the two sides can now be understood, for here the arc burns only more or less laterally.

The peculiar form of the penetration with contact electrodes is in very many cases of the greatest importance, for the following reasons. In the first place the deep penetration in the middle makes it possible with V-welds (and of course with fillet welds made in the flat position) to apply a first layer directly with a heavy contact electrode, say with a core diameter of 5 or 6 mm. It is unnecessary to deposit a first layer with an electrode of small diameter. The result is fewer layers and saving of time, as well as other advantages (*cf.* below on the subject of distortion).

It is to be noted that with a certain diameter of Contact 15 the arc voltage is closely dependent on the current used: with high current the arc voltage is highest. *Fig. 2* shows the relation between arc voltage and current for contact 15-5. (The number 5 indicates the diameter of the core wire in mm.) As was to be expected, the penetration is also found to depend very much on the current [8]).

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7) As stated in the article referred to in footnote [1]), in special cases it is more advantageous to use Contact 15 with the free arc; this is also true for Contact 18.

8) See J. Sack, Philips Techn. Rev. **4**, 9, 1939 and the Welding Industry, July 1939.

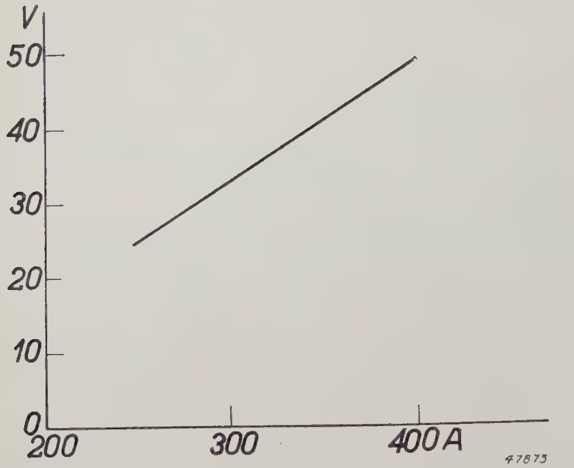


Fig. 2. Relation between arc voltage and current for Contact 15-5.

When a fillet weld is made in the flat position with two strips of 12 mm thickness, successively with different currents, and the depth of the penetration, the so-called root penetration (see text below *fig. 3*), is measured on the cross-sections, the result shown graphically in *fig. 4* is obtained. A similar graph could also be drawn for V welds; the relation between the current and the root penetration would be found to be qualitatively the same. It is therefore clear that when making, for instance, an open V weld with backing strip (see *fig. 5*) and using Contact 15-6 a high current must be used for the first layer in order to secure sufficient penetration to the bottom of the weld.

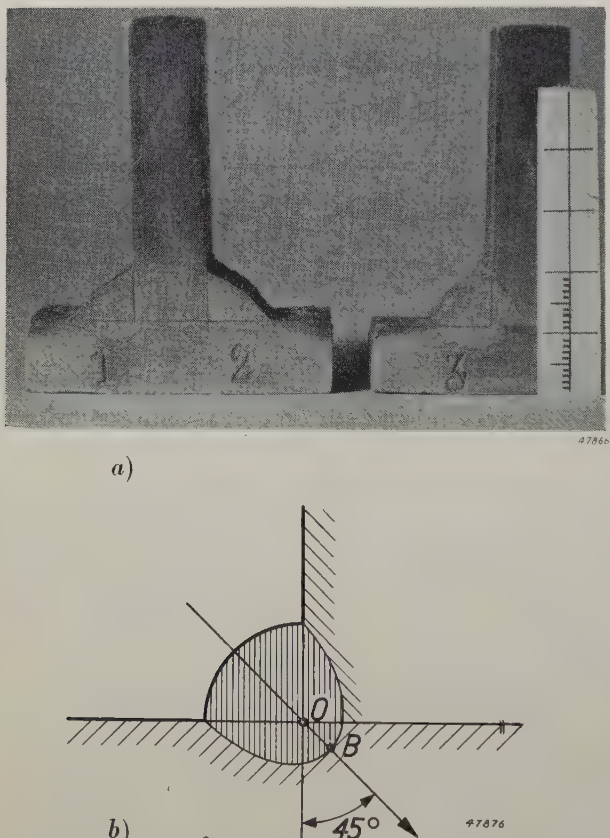


Fig. 3. *a*) In these cross-sections of fillet welds made in the flat position it is clearly seen that the depth of the penetration depends upon the current: the currents in the cases shown as 1, 2 and 3 amounted, respectively, to 375, 300 and 440 amp; the unit of the scale corresponds to 1 cm.
b) The strength of the weld is to a large extent determined by the so-called root penetration, which is defined as the distance *OB*. The root penetration is considered positive in the direction of the arrow. A negative root penetration means that a channel remains open in the corner under the bead.

In the second place, due to the slight penetration at the sides, even when the heaviest contact electrodes and the highest currents are used,

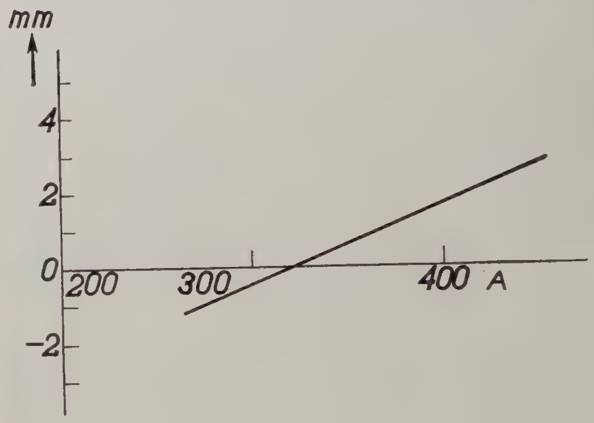


Fig. 4. The relation between the root-penetration and the current used with Contact 15-5, found from fig. 3.

no trouble is experienced from undercut, *i.e.* burning away of the original material at the edges of the bead. Undercut is one of the difficulties that had to be combatted with ordinary electrodes at high currents; undercut reduces the strength of the welded joint.

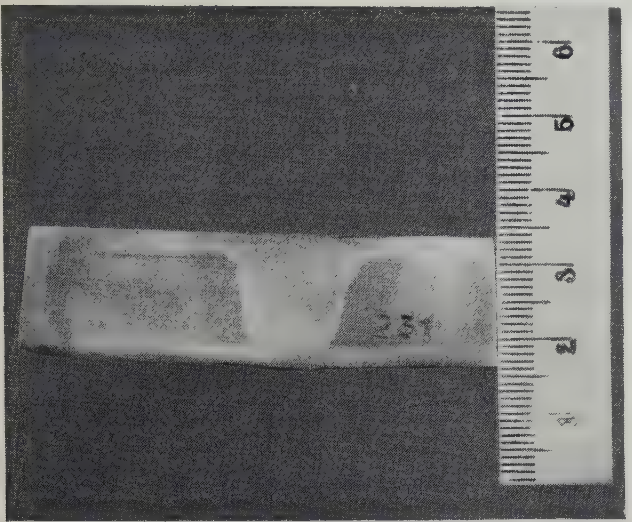
Fig. 6 shows fillet welds made in the flat position with Ph. 55-7 (No. 59) and with Contact 15-5 (No. 76), both with alternating current, 375 amp., 30 volts and 375 amp., 42 volts, respectively. The undercut can clearly be seen in No. 59 (under the 9 for instance). *Fig. 7* shows two cross-sections taken from these welds; with Contact 15-5 (No. 76d) the root penetration is about 1.5 mm deeper than with Ph. 55-7 (No. 59b).

To sum up, it may be stated that the shape of the penetration as found with the heavier contact electrodes offers important technical advantages compared with that obtained with ordinary coated electrodes.

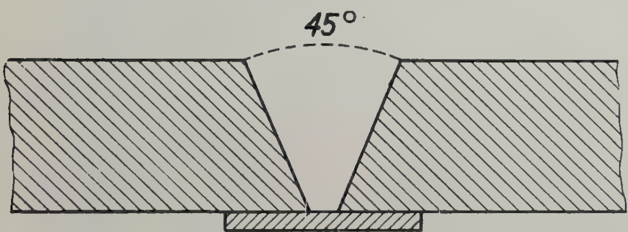
Welding speed

It has already been mentioned that the arc voltage of contact electrodes, especially those of

5 mm and heavier, is considerably higher than that of the corresponding ordinary electrodes. In the course of the investigation it was also found that the heat efficiency of the contact electrodes, *i.e.* the ratio



a)



b)

Fig. 5. *a*) Diagram of an open V weld. In the case represented in the photograph (see *b*), the angle was 45° and the opening, *i.e.* the smallest distance between the two plates to be joined, was 4 mm.

b) Cross-section of an open V weld made in two layers between two plates 17 mm thick. For the first layer Contact 15-6 was used with 520 Amp. A.C.; for the second layer Contact 15-6 with 490 Amp. The backing strip is removed after welding.

of heat expended in the fusing of the metal to the total amount of heat supplied, is higher. This is due to the deep cup enveloping a larger part of the arc than is the case with ordinary electrodes used with the free arc. The heat in the arc is thus used to greater advantage and the radiaton of the arc into space is diminished. As a result of the two facts mentioned, the welding speed, *i.e.* the amount of metal deposited per second, is considerably higher with the contact electrodes.

Averaged over a large number of tests it was found, for example, that Contact 15-5 is about 50% faster than Ph. 55-7. These diameters of the two types are particularly suitable for comparison because they contain equal amounts of iron and slag-forming substances [9]), and because incidentally the maximum current is the same in both cases, namely about 375 amp.

Table I gives the average results:

Table I

Electrode	Contact 15-5	Ph. 55-7
Current in amp.	375	375
Arc voltage	42	30
Milligrams iron per sec.	1700	1150
Milligr. iron per amp. sec.	4.5	3.1

In addition to this greater speed of Contact 15 compared with an ordinary coated Ph. 55 of the same weight, there is also the possibility, already mentioned in the discussion of the shape of the penetration, of using a heavier contact 15 in many cases where a lighter type of an ordinary coated electrode would be required. This also means greater welding speed, since with a heavier electrode more iron is deposited per second. Therefore in such cases this gain in speed must be added to the above 50%.

Several further particulars

Distortion

The distortion or warping of a weld may have unpleasant results in all welded structures and the avoidance of this demands much care and expert knowledge. It is therefore of great importance that in welding with contact electrodes there is little distortion. This fact is very closely connected with the high welding speed and the favourable shape of the penetration of these electrodes. It is known that distortion increases as the welding speed decreases and also increases with the number of layers in the weld. It has already been explained that in welding with contact electrodes, due to the special shape of the penetration, fewer layers are needed than in the case of ordinary electrodes.

Heating of the electrodes

In many cases, and especially with the lighter electrodes [10]), the highest permissible current is

[9]) At low currents when the arc voltage is not higher than with Ph 55, a smaller penetration might even be expected with Contact 15.

[10]) With heavier types the highest current is determined by other factors, for instance by the desired uniformity of the surface of the weld, which becomes less at higher currents (convex, irregular appearance).

determined by the fact that when using up the last piece of the electrode the top end becomes red hot and this is apt to cause the rod to bend. Since it might, therefore, be expected that the highest permissible current for contact electrodes would be much lower than that for ordinary ones, but

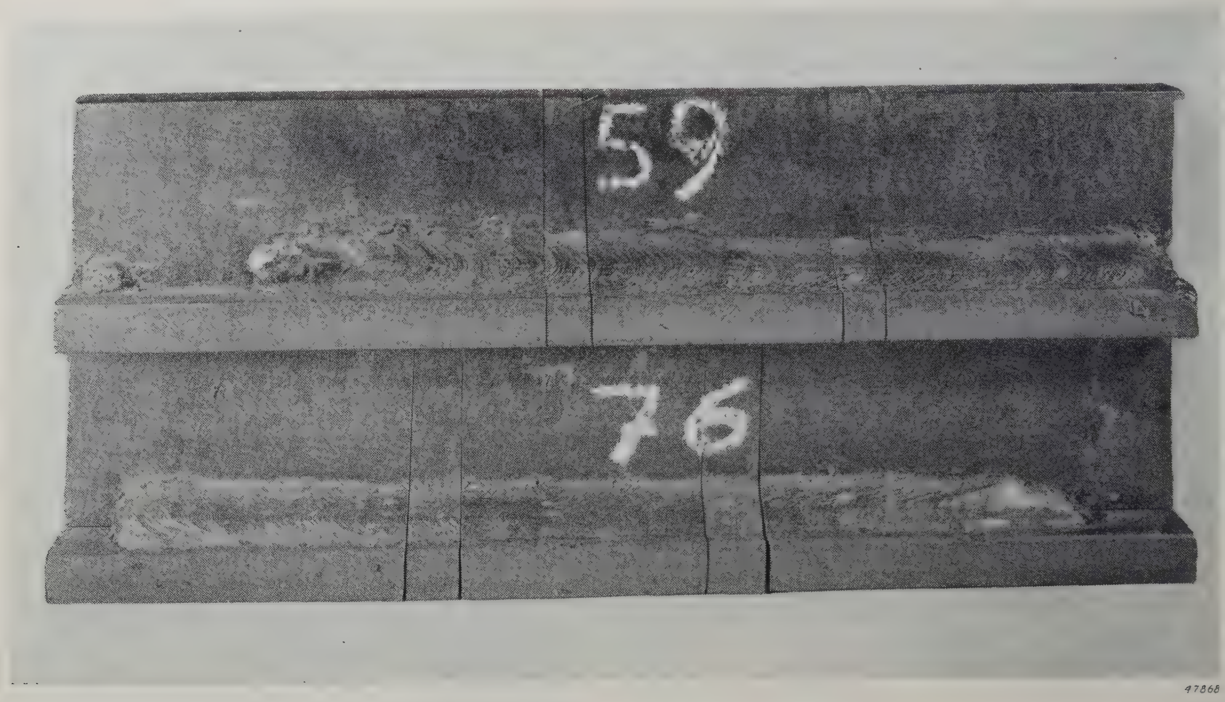


Fig. 6. Photographs of fillet welds made in the flat position with Ph 55-7 (No. 59) and with Contact 15-5 (No. 76). In No. 59 the undercut can be seen under the figure 9, while No.76 shows no faults at all.

the cores of contact electrodes are much thinner than those of the corresponding ordinary electrodes actually there is not such a great difference. Thanks to the fact that the coating of the contact electrodes is heavy and conductive, it dissipates the heat much better than the coating of the ordinary electrodes, thus compensating for a large part the effect of the smaller thickness of the core wire of the contact electrodes. Whereas with ordinary electrodes it is of only secondary importance whether or not the coating makes good contact with the holder, in the case of contact electrodes it is of great importance that the coating should make good contact with the holder, because otherwise the upper end of the core wire would become red hot much sooner than in the case of an ordinary electrode. The holder should have a reasonably high heat capacity and conductivity; the heads of holders specially made for contact electrodes are of copper and constructed in such a way as to fulfil this requirement.

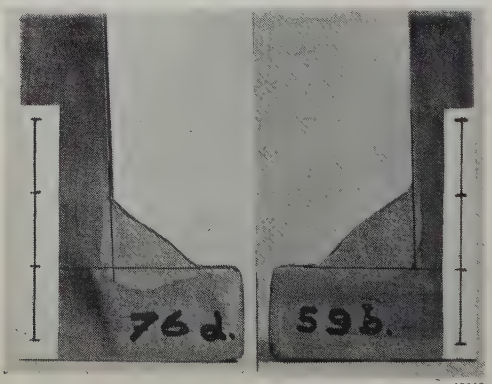
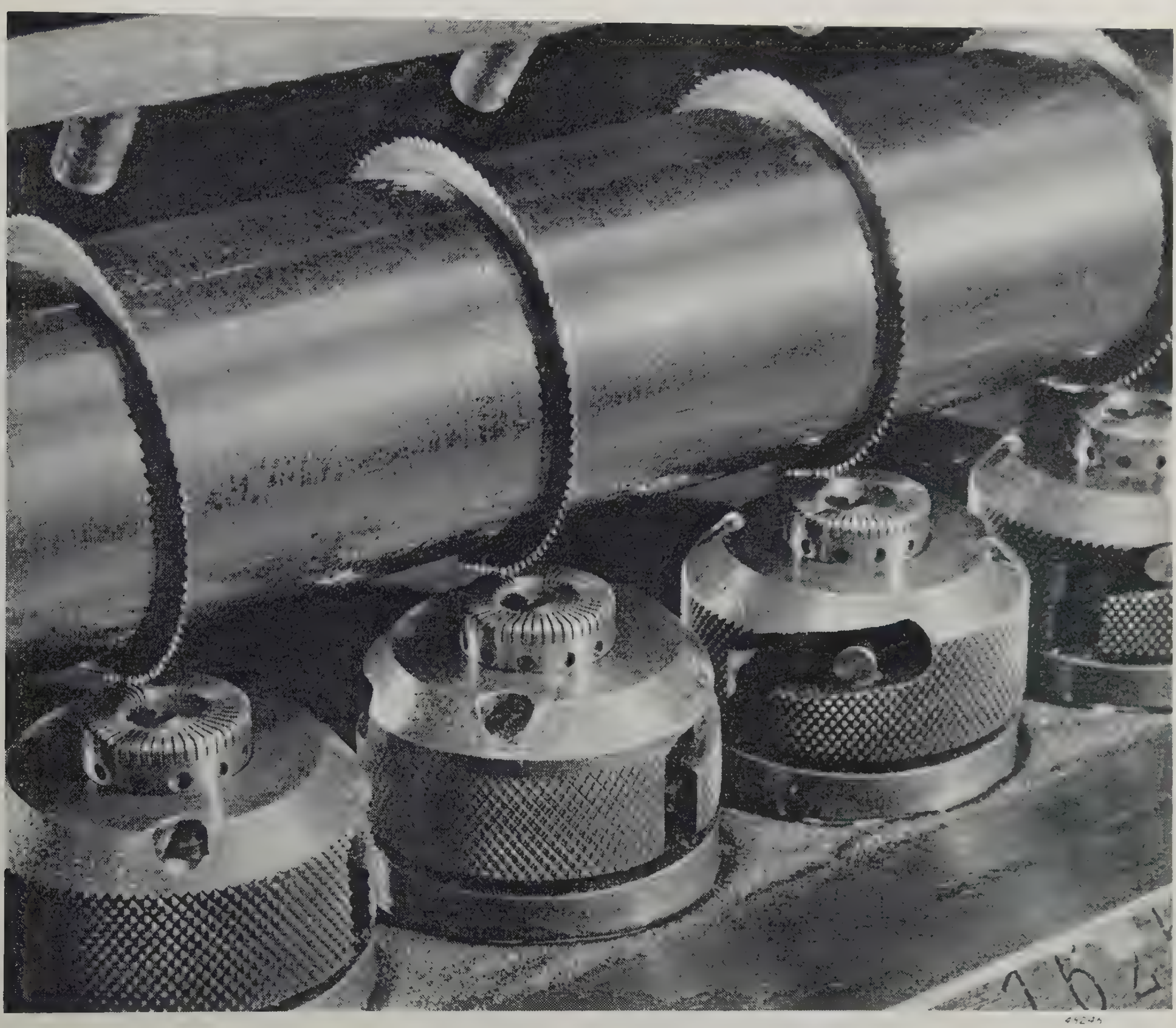


Fig. 7. Cross-sections of the fillet welds of fig. 6. In 76d, which was welded with Contact 15-5, the root penetration is found to be about 1.5 mm deeper. The unit of the scale corresponds to 1 cm.

MASS PRODUCTION OF ELECTRICAL SHAVERS



This photograph shows how the 48 slots are cut in the head of the "Philishave" dry-shaver. A series of circular saws are clamped at equal distances around a rotating shaft and underneath each saw is a special kind of turntable on which a shaving head is placed. These tables are carried on a common slide moved in the direction of the saws. As soon as the slide has passed underneath the saws and a slot has been cut in each head, the slide returns and all the tables automatically turn exactly over the forty eighth part of a circle, ready for the next slot to be cut.

AUTOMATIC CHANGE-OVER TO AN EMERGENCY APPARATUS IN A COMMUNICATION SYSTEM

by G. HEPP.

621.395.365.3

In the case of a breakdown it should be possible for components of a communication system, such as amplifiers and oscillators, to be replaced automatically by analogous emergency components without interruption in the service. In particular the impulse generator, from which the carrier waves of a carrier telephony system are derived, has to satisfy very high requirements as regards safety precautions. Here two methods are described that have been developed by Philips for automatic changeover to an emergency component as soon as the amplitude of the output signal falls below a certain value. One of these methods is employed in a carrier telephony system already described in this periodical. Where low-frequency amplifiers are concerned, which — in contrast to oscillators — produce an output signal varying considerably in amplitude, a constant auxiliary signal is added which has a frequency outside the band of the signal to be amplified. It is this auxiliary signal which brings about the change-over to the emergency amplifier when the intensity becomes too low.

Introduction

In the present stage of electrical communications technique — whether it is a question of an "ordinary" telephone connection or one with carrier system, a cable or a radio connection — the message transmitted passes through numerous electrical apparatus: lines, transformers, amplifiers, etc., and the development of this technique is undoubtedly moving in the direction of greater complexity of the whole system; witness the carrier-wave telephony repeatedly discussed in this periodical. With this greater complexity there is, of course, a greater chance of failures due to defects, which are never entirely avoidable. On the other hand, and rightly, in communications technique very high requirements are set as to reliability requirements which not only call for the utmost care in manufacture, testing and maintenance, but which, moreover, make it necessary to apply measures for limiting failures, which in spite of everything are still apt to occur occasionally, to the shortest possible duration — preferably so short as to pass unnoticed by the persons who are connected. It is usually not sufficient to install an alarm arrangement to warn the operators in case of emergency. Often a certain component will have to be duplicated and a device installed for automatically changing over to the emergency part as soon as a failure occurs. This change-over must be effected with the minimum number of extra parts, because they too may be liable to breakdown. Further requirements which such an arrangement must satisfy will be discussed farther on.

Obviously it will depend upon the importance of a component how far these safety measures will be carried. A typical example of a component which in case of a breakdown — if no emergency reserve is provided — would lead to the simultaneous interruption of a number of connections is the impulse generator, recently discussed in this periodical, which furnishes a carrier system with carrier waves [1]). It is essential that there should be an emergency generator to be automatically switched on without interruption in case of breakdown, while of course the operators have to be warned too. Such an automatic transfer is especially necessary for apparatus located where there is no operating personnel, as is the case, for example, with most repeater stations, which are located at regular intervals along a telephone link.

We shall now discuss in turn some of the requirements which such an arrangement has to satisfy and examine how this can be achieved. First of all, however, let us define the term "failure" as signifying a fall in the output voltage to below a certain limit (for instance 80% of the rated value). For the present we shall consider only those components which, like a generator, give an approximately constant voltage when functioning normally. Later we shall also discuss components where this is not the case (for instance low-frequency amplifiers).

First requirement: metastability

If the output voltage falls below the critical value the emergency generator must be switched in, but if that voltage subsequently rises again to above that level the regular generator must still remain out of service until the defect has been repaired and it has been restored to action by the operating personnel. If this requirement were not fulfilled then every time a bad contact is made or a contact broken there would be a change-over from one generator to the other, which would cause a troublesome clicking in the telephones. The possibility of such an unnecessary change-over taking place is not confined to the case of a loose contact, for it can well be imagined that due to ageing of the valves the output voltage may fall to round about

[1]) The Excitation of the Carrier Waves in an Installation for Carrier Telephony, Philips Techn. Rev. 8, 141, 1946.

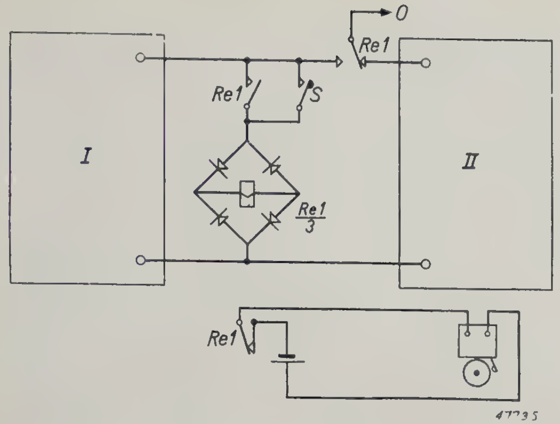


Fig. 1. Automatic change-over and alarm by means of a relay *Re*1/3, see footnote [3]). After pressing the starting key *S* the coil of the relay is excited by the rectified voltage from the generator *I*. This causes the three relay contacts to change from the position indicated to the opposite one, so that
1) the load *O* is connected with generator *I*,
2) the key *S* is shunted, so that after *S* is released the relay coil continues to be excited,
3) the alarm arrangement is switched off.

When generator *I* fails, the relay opens and the contacts return to the positions drawn in the figure, so that
1) the load *O* is connected with the emergency generator *II*,
2) the key is no longer shunted.
3) the alarm comes into action.

If generator *I* recovers, the conditions last mentioned are maintained (metastability) until the key *S* is pressed down again.

the critical value and owing to fluctuations in the mains voltage sometimes be above and sometimes below it.

A circuit which satisfies the requirement first formulated is said to be metastable. *Fig. 1* is an example of how this can be realized with the help of a relay [2]); its functioning is explained in the text below the illustration.

Further requirements

A second requirement is that the transfer apparatus must not use too much energy from the generator. The excitation of a reliable relay requires more power than can be spared for that purpose by most generators, and especially by those used for carrier telephony. An amplifier valve might be used in front of the relay, but this is apt to conflict with the requirement, mentioned at the beginning, that there should be the minimum number of parts subject to breakdown themselves.

To avoid these difficulties two circuits were designed in which one or more of the valves of the generator also fulfils the function of D.C. amplifier for the relay. These circuits differ in the fact that in the one case the combination of the two generators is mestastable, and in the other each separate generator is metastable. By way of example the two circuits will be discussed as applied to simple oscillators.

Circuit in which the combination is metastable

Fig. 2 shows a circuit in which one oscillator furnishes a voltage which, when rectified, blocks the other [3]). Only one of the two oscillators can function at one time, and if that one fails, the other comes automatically into action without the use of a relay. An alarm relay will of course be used (not drawn in fig. 2).

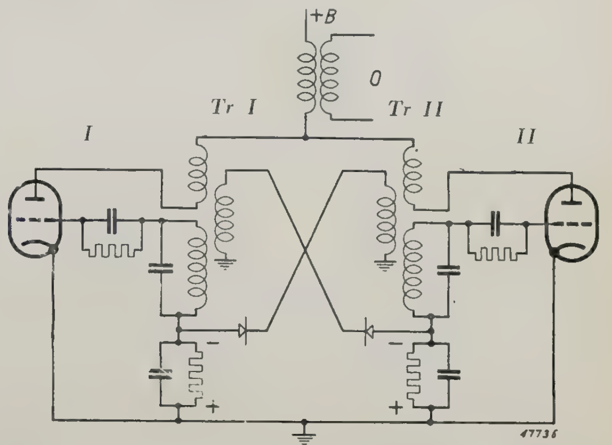


Fig. 2. Circuit in which one oscillator (*I*) excites in an extracoil of the transformer *Tr I* a voltage which, being rectified, blocks the oscillator *II* and inversely. With this arrangement no relays are needed to transfer the load *O*. Relays for alarm signals are omitted for the sake of simplicity. At $+B$ anode voltage is connected.

The circuit of fig. 2 still has the drawback that in the event of the anode being short-circuited with earth or one of the other electrodes neither of the two oscillators can work. This objection can be met by replacing the output transformer by two somewhat more complicated transformers, as indicated in *fig. 3* (*TrA* and *TrB*). If we assume that oscillator *I* is in action, its anode current flows through the two coils *1* of *TrA* and *TrB*, respectively, and induces voltages in all the other coils. These are so connected that the voltages in
coils *2* cancel each other, so that in the anode circuit of *II* no voltage is induced (a possible short-circuiting of anode *II* to earth does not then affect the energy furnished by *I*);
the voltages in coils *3* act together so that there is a result ant voltage which blocks *II*;
the voltages in coils *4* cancel each other, so that *I* does not block itself.

Owing to the symmetry of the circuit the same applies, *mutatis mutandis*, when *II* and not *I* is the oscillator in function.

[2]) In the diagrams of this article where relay coils are denoted, for instance, by *Re* 2/4, the first number is the number of the relay in question and the second the number of contacts it has. Each relay contact is indicated by *Re* followed by the number of the relay to which the contact belongs. According to custom the contacts are drawn in the position occupied when the coil carries no current.

[3]) U.S. Patent 2.319.320. This circuit is related to the circuit known as "Kallirotron", in which, however, the D.C. voltage that blocks one valve is taken directly from the other without the intermediate stage of a rectified A.C. voltage; the object in this was to produce a negative resistance.

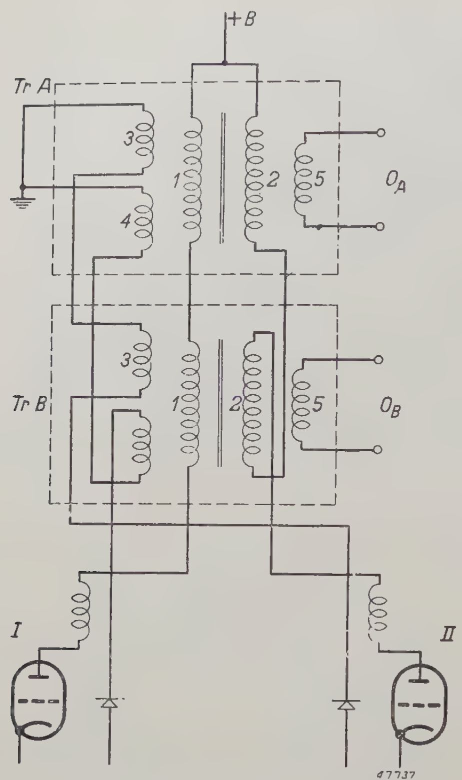


Fig. 3. Extension of the circuit of fig. 2 to include two push-pull output transformers (*Tr A* and *Tr B*), so that when an anode is short-circuited to earth one of the oscillators continues to function. The load must be divided equally between the two coils 5 (O_A, O_B).

The two coils 5 are the output coils, each of which feeds half of the load. The condition for good functioning is that these loads shall be equal, since otherwise the balance is upset.

Circuit in which each of the oscillators is metastable

Fig. 4 shows a circuit [4]) in which initially each of the oscillators is kept blocked by the negative grid voltage from a battery *C*. This blocking voltage can, however, be neutralized by an equal but oppositely directed voltage *E*. The voltage *E* for each of the oscillators is obtained by rectification of an A.C. voltage induced in an auxiliary winding on their output transformer (*TrI* and *TrII*, respectively). Once it is brought into action, therefore, the oscillator continues to generate, but it cannot begin of itself, so that the requirement of metastability is met. In order to start, the key S_I or S_{II} is pressed down, temporarily cutting out the negative grid voltage, so that the valve begins to generate, and when the voltage *E* has been reached the key can be released without any change occurring. Normally both the oscillators function, but only the voltage generated by one of them is used.

In the anode circuits there are the relays *Re1/2* and *Re2/1*, each of which operates an alarm contact, while the former also operates the switching-over of the load *O*. The relay coils are excited by the anode direct current. The energy taken from the output transformer to set up the voltage *E* is naturally much less than the energy necessary to excite the relay.

The relay *Re2/1* can be omitted if necessary, but its retention has the advantage that a warning is also given when there is a failure in the emergency oscillator *II* while it is in a state of oscillation but not in action, thus considerably enhancing the reliability of the emergency unit. In the circuit of fig. 2 such a possibility is entirely absent. In cases where absolute dependability is essential, therefore, the circuit of fig. 4 will be preferred to that of fig. 2 (and the use of relays will have to be accepted). If the requirements are less strict the simpler method of fig. 2 will receive first consideration.

Temporary interruption of metastability; automatic starting

It may happen that both oscillators fail simultaneously due, for instance, to a short interruption of one of the feeding voltages — or that they fail one shortly after the other, without any serious defect in either. The service would then be completely at a standstill. In such an event metastability plays us false and it is therefore necessary to try

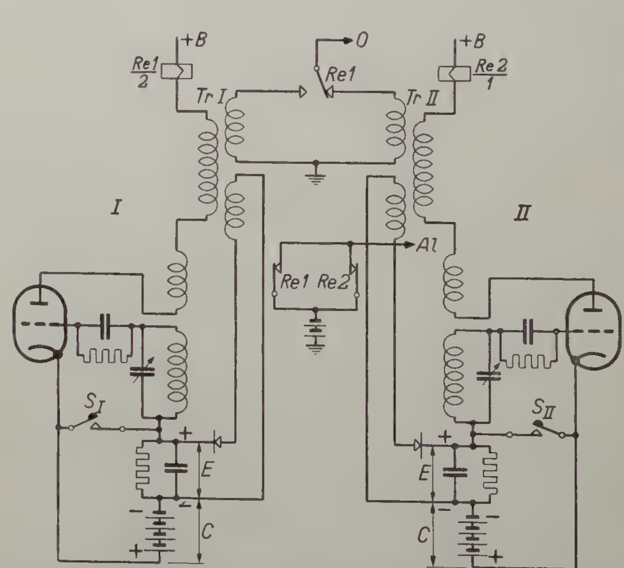


Fig. 4. Circuit in which each of the identical oscillators *I* and *II* excites its own grid voltage *E* equal to the fixed negative grid bias *C* but of opposite polarity. Consequently each of the oscillators is metastable, *i.e.* they cannot be brought into action without pressing the starting keys S_1 or S_{II}. The relays *Re* 1/2 and *Re* 2/1 switch over the load *O* or respectively bring an alarm into action. $+B$ = positive pole of the anode battery, *Tr I*, *Tr II* = output transformers, *Al* = alarm arrangement.

[4]) U.S. Patent. 2. 330. 582.

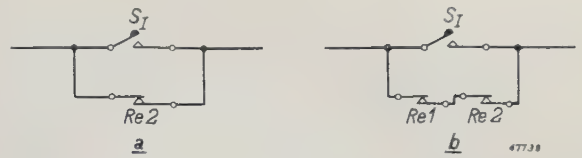


Fig. 5. *a*) The starting key S_I of oscillator *I* being shunted by a break-contact *Re* 2, oscillator *I* (when oscillator *II* has failed), can of itself come into action again after a momentary failure. Conversely S_{II} is also shunted by a break-contact *Re* 1.

b) When oscillator *I* is functioning normally, a faulty contact in oscillator *II* would cause relay contact *Re* 2 to open and close (fig. 5*a*), which might have undesirable consequences. In order to avoid this, a break-contact *Re* 1 is connected in series with *Re* 2. S_{II} is also shunted by a connection in series of two break-contacts *Re* 1 and *Re* 2.

to neutralize it when one of the oscillators fails.

This can be done in the manner indicated in *fig. 5a*, namely by shunting the starting key S_I by a break-contact of *Re 2/1* (and conversely by shunting S_{II} by a break-contact of *Re I/2*). After a temporary disturbance oscillator *I* can then resume action without outside help.

A slight addition, however, is still desirable. If, while oscillator *I* is in action, "chattering" occurs in *II*, the relay contact *Re 2* in parallel with S_1 would continually open and close. This would be harmless if the voltages *C* and *E* were exactly equal, but this is only approximately so (due in part to the fact that *E* decreases as the valves age). The adjustment of the valve *I* therefore changes somewhat as the relay contact opens or closes, resulting in undesired fluctuations in the oscillator voltage.

This can be avoided by connecting in series with the above-mentioned relay contact another break-contact of relay *Re 1/2* (*fig. 5b*). This is open as long as oscillator *I* is in action, so that the opening or closing of the contact *Re 2* in series with it has no effect. Conversely, the other starting key is shunted by two break-contacts in series, one of relay *Re 1/2* and one of relay *Re 2/1*. The two pairs of contacts are closed when both oscillators are out of action; these are thus given the opportunity of beginning to oscillate anew (as far as they are in a condition to do so), without it being necessary to press the starting key. This is what is called automatic starting.

Practical example

In a carrier-wave system designed by Philips automatic change-over of the impulse generators

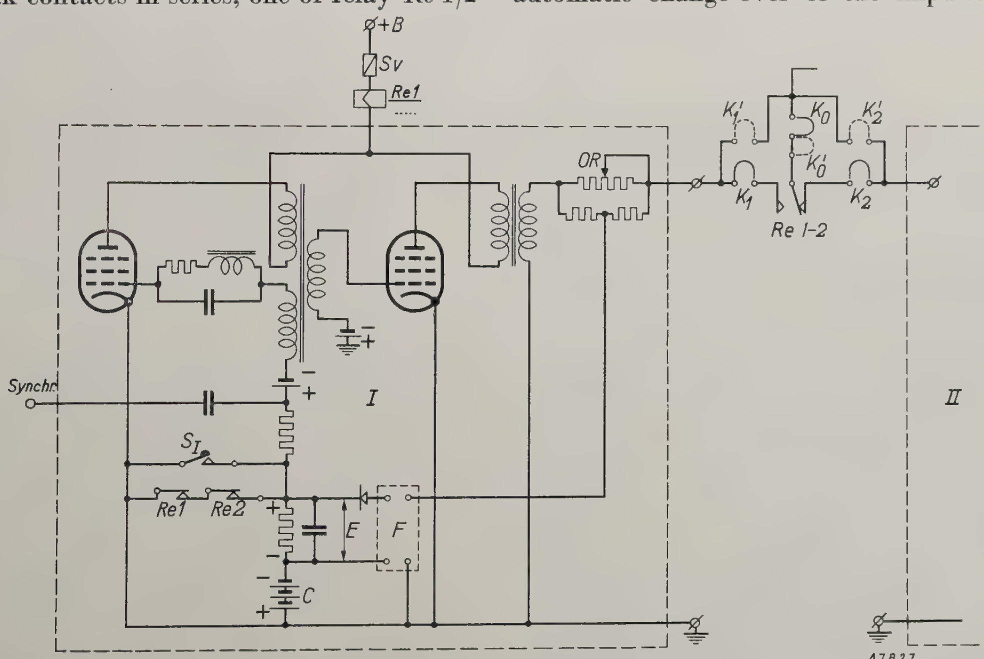


Fig. 6. More detailed diagram, on the principle of fig. 4, of the impulse generator for a telephony system with carrier waves.
F = filter tuned to the fundamental frequency (4Kc/Sec), *Synchr.* = connection for the synchronizing voltage, *OR* = signal volume control, *Sv* = Safety fuse, *Re* 1-2 = relay contact connecting the load either with generator *I* or with generator *II*. It is indicated in this way because the relays *Re*1/2 and *Re*2/1 of fig. 4 can be exchanged at will by a switching arrangement (not shown). In this way one is free in the choice of which generator will be considered the regular one. This change-over is done by means of the control key of fig. 7. K_0, K_1, K_2 = plug connections to make the installation independant of the contact *Re* 1-2, If this checking has to take place during the operating of Osc. *I* the plug is taken from K_2 and placed in the position K_1'. Subsequently the plug *K* in the position K_0 is brought into the position K_0' and finally the conection between *Re* 1-2 and the Osc. *I* is broken by removing the plug from *K*1 and spring it temporarily in the position K_2.

is employed on the principle of fig. 4. The circuit used is given in somewhat more detail [5]) in *fig. 6.* The grid voltages C and E referred to in the foregoing may be distinguished, and also the starting key S_1 shunted by two relay contacts according to fig. 5*b*. The filter (F), however, is new; the voltage E with which the generator unblocks itself should only come through when the desired signal is produced and not, for example, a "hum" or some chance oscillation. To this end a filter or circuit (F), tuned to the fundamental frequency of the A.C. voltage to be provided (here 4 kc/sec), is placed in front of the rectifier cell which furnishes the voltage E.

Fig. 7 shows the key panel. The function of some of the keys is explained in the text below the figure.

Automatic change-over of audio-frequency amplifiers

The methods of automatic change-over described, both those of fig. 2 and those of fig. 4, are based on the rectification of an A.C. voltage proportional to the signal emitted and the use of this rectified voltage either to block the other oscillator (fig. 2) or to deblock its own oscillator (fig. 4). This works satisfactorily as long as it is applied to an apparatus that gives a reasonably constant signal. In the case, however, of an amplifier for speech or music, for instance, the output voltage is

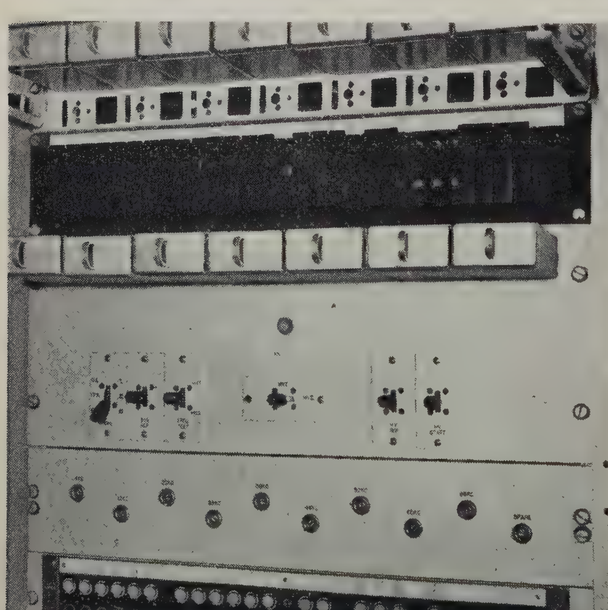


Fig. 7. Key panel for carrier wave feeding with automatic transfer according to fig. 6. The central key is used to determine which generator will be the regular one and which the emergency. The key at the extreme right is the starting key (S_I or S_{II}, according to the position of the central key). The key second from the right, in the position "M.V. Repair" during repair of the emergency generator, also switches off the alarm of the latter.

[5]) This diagram is at the same time an elaboration of figs. 2 and 5 of Philips Techn. Rev. **8**, 140 and 143, 1946.

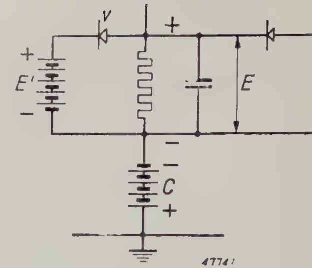


Fig. 8. When the principle of fig. 4 is applied to low-frequency amplifiers the blocking voltage E has to be limited (upward) to maintain the correct operating conditions of the amplifier valve. This limitation can be achieved by employing a battery with voltage E' in series with a rectifier cell v which passes current when E becomes higher than E'.

most variable and at intervals even zero. If either of the methods described were applied to such an amplifier, then the intervals and even the soft passages would cause the transfer mechanism to act as if there were a defect, thus leading quite unnecessarily to repeated change-over.

This can be avoided in the following way. In addition to the low-frequency signal to be amplified, a constant auxiliary signal of a frequency lying outside (usually higher than) the band to be amplified is laid on to the input of the amplifier. This auxiliary signal is always present and gives at the output the necessary blocking or deblocking voltage for the amplifier valve or valves. A filter F as in fig. 6, tuned to the frequency of the auxiliary signal, is of course indispensable.

If this is applied in a circuit like that of fig. 4, it is necessary to introduce a limitation of the voltage E, because in contrast to the case with the impulse generator with low-frequency amplifiers only a small part of the valve characteristic is used, so that the operating conditions must remain constant within narrow limits.

If for some reason or other the voltage E should become too high, the valve will function in a region with a larger mutual conductance and the output signal will also become greater, which causes E to increase again, and so on. In order to prevent this one can connect in parallel with the resistance and condenser on which the voltage E acts (*fig. 8*) a battery of the desired voltage E, in series with a rectifier cell v which passes current when E becomes higher than E'.

By this means E is limited to the value E'. If, due to a defect, E falls below the value E', the cell v keeps the battery switched off as it were, so that E can drop unhindered and finally the amplifier in question is cut out. Under normal conditions, however, E is practically equal to E', so that the operating conditions of the amplifier valve are confined within narrow limits.

NON-FERROUS COPPER WIRE FOR MOVING-COIL METERS

by P. G. MOEREL and A. RADEMAKERS. 621.317.715.004.64:538.22

The material of which the rotating system of moving-coil meters is made may contain particles of iron. The ferromagnetism of the latter, in combination with the express or accidental inhomogeniety of the magnetic field, causes certain defects in the measuring instrument, such as a non-reproducible zero point or, in the case of coulometers too large, a residual couple. Measures are discussed particularly for keeping the copper wire used for the moving coil as free of iron as possible, and some results thereby obtained are mentioned.

Moving-coil meter without directional couple

As far back as the beginning of this century it was known that a magnetic flux or a quantity of electricity ($\int i\mathrm{d}t$) can be measured with the help of a moving-coil meter provided it satisfies certain requirements. Such an instrument is the fluxmeter of Grassot [1]).

The main requirement to be satisfied, contrary to what is demanded of an ordinary moving-coil meter, is an extremely small directional couple.

This follows from the equation of motion of the moving system:

$$J\frac{\mathrm{d}^2\varphi}{\mathrm{d}t^2}+a\frac{\mathrm{d}\varphi}{\mathrm{d}t}+D\varphi=Ai \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where J represents the mass moment of inertia with respect to the axis of rotation, φ the angle of rotation, t the time, a the damping constant, D the directional couple at $\varphi = 1$, A a proportionality factor and i the current in the rotating coil. This equation expresses the fact that the external couple (Ai) is at equilibrium with the resultant of the couple of the mass force, the damping couple and the directional couple.

If the instrument possesses a sufficiently small inertia and directional couple, such that the first and third terms of the left-hand member of (1) are negligible compared with the second term, there remains:

$$a\frac{\mathrm{d}\varphi}{\mathrm{d}t}=Ai \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Or integrated:

$$\varphi_1-\varphi_0=\frac{A}{a}\int_{t_0}^{t_1} i\mathrm{d}t=\frac{A}{a}Q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The difference between the readings at the moments t_1 and t_0 is thus a measure of the charge Q which has flowed in that interval of time.

In the complete absence of directional couple and inertia the coil only moves while current is flowing through, but has no definite zero position. If the moments t_0 and t_1 of (3) are chosen before the beginning and after the ending of the passage of current (which will naturally be the case when dealing with a current impulse), φ_0 and φ_1 are read when the pointer is stationary. This is one of the advantages of this method compared with the ballistic method, where the largest deviation has to be read.

The current i in the right-hand member of (2) may be an impulse generated by the change in flux in a coil to which the instrument is connected. Then

$$i=\frac{1}{R}\cdot n\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

(R = total resistance of the circuit, n = number of windings of the coil, each of which envelops the flux Φ), so that the solution of (2) becomes

$$\varphi_1-\varphi_0=\frac{A}{a}\cdot\frac{n}{R}(\Phi_1-\Phi_0) \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If the change in flux is obtained, for instance, by sliding the coil off a magnet under examination, then Φ_0 is the flux to be determined and Φ_1 is practically zero, so that here again the change in reading is a measure of the quantity desired.

The directional couple is kept small in the first place by entirely omitting the spiral springs which cause this couple in ordinary moving-coil meters, and further by leaving the connection wires to the moving-coil limp and balancing the moving system as truly as possible. It has, however, long been known that often a small directional couple still remains [2]), as a result of which the pointer does not become stationary after the conclusion of the current impulse. This "parasitic" directional couple is to be ascribed to a combination of two causes, *viz.* the presence of ferro-magnetic impurities [3]) in the materials of which the moving coil is made, in combination with the fact that the magnetic field in which the coil moves is not entirely homogeneous (although that is usually desired). If the coil contains particles of iron large enough to exhibit ferromagnetism [4]), those particles are attracted

[1]) E. Grassot, Fluxmètre, J. Phys. **3**, 696, 1904.

[2]) H. Busch, Das Kriechgalvanometer, Zt.f. techn. Physik, 7, 369, 1926.

[3]) See for example F. W. Constant, Ferromagnetic Impurities in Metals, Rev. Mod. Phys. **17**, 81, 1945, where further references to literature are also given.

[4]) As is known, ferromagnetism is based upon a reciprocal action between iron atoms (or nickel or cobalt atoms). It does not occur in the case of iron atoms in solution among other atoms, at relatively large distances from each other.

to the spots where the field strength is greatest, so that a couple acts on the rotating system and consequently when it is carrying no current it still shows a certain preference for a definite position.

Parasitic directional couple caused by ferro-magnetic impurities

This is illustrated by *fig. 1*. Even when the iron core between the pole pieces is perfectly centred the field in the air gap is not absolutely homoge-

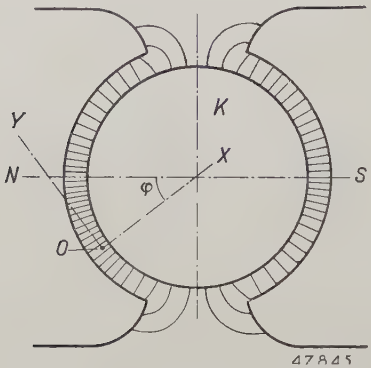


Fig. 1. Not entirely homogeneous field distribution between the iron core K and the pole piece N-S of a moving-coil meter.

neous, because of the spreading of the lines of force at the edges of the pole pieces; it is strongest on the N-S axis. A ferromagnetic particle of iron at point O becomes a (practically) radially directed magnetic dipole and will experience a force which tends to move it towards the position of greatest field strength, thus in the direction of the y axis indicated in fig. 1. This force leads to a couple which is found to be proportional (see below) to the imhomogeniety of the field, which is expressed by $\partial H_r/\delta\varphi$. Added together over all the ferromagnetic particles of iron situated in the magnetic field, whose combined mass we shall call G, this leads to a couple

$$K_{\mathrm{Fe}} = CG \cdot \frac{\partial H_r}{\partial \varphi} \quad . \; . \; . \; . \; . \quad (5)$$

acting on the rotating system, where C is a constant.

For the component in the Y direction of the force F which a magnetic field H (with components H_x, H_y, H_z) exerts on a dipole with the magnetic moment M, the following applies:

$$F_y = M_x \frac{\partial H_y}{\partial x} + M_y \frac{\partial H_y}{\partial y} + M_z \frac{\partial H_y}{\partial z}.$$

In the case in question where the dipole is (practically) radially directed, $M = M_x$ and $M_y = M_z = 0$, thus,

$$F_y = M \frac{\partial H_y}{\partial x}.$$

The components F_x and F_z in the first instance have no effect on the deflection of the measuring instrument and therefore are not considered here.

In the absence of electric current rot $H = 0$; in another form this is expressed by three equations, one of which is as follows:

$$\frac{\partial H_y}{\partial z} = \frac{\partial H_x}{\partial y},$$

so that the following may be written for F_y:

$$F_y = M \frac{\partial H_x}{\partial y};$$

thus on the moving coil of diameter d a couple k acts of the following magnitude:

$$k = \frac{d}{2} M \frac{\partial H_x}{\partial y} = M \frac{\partial H_r}{\partial \varphi} \quad . \; . \; . \; . \; . \; . \quad (6)$$

when φ is the angle indicated in fig. 1.

In order to arrive at the total couple K_{Fe} exerted on the moving system due to the presence of particles of iron, (6) must be totalled up for all the particles concerned. Assuming that, roughly speaking, all these particles are situated in an equally strong field, with the same inhomogeniety, and that they are similar in shape, the total couple is found to be proportional to their combined mass G. If the other factors are included in a single constant C, the following is indeed obtained:

$$K_{\mathrm{Fe}} = C \cdot G \cdot \frac{\partial H_r}{\partial \varphi} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

The effect in question is thus dependent on two factors which one can try to influence; the amount of iron impurities in the coil and the inhomogeniety of the field (G and $\partial H_r/\partial\varphi$ in (5)).

Fig. 2a shows diagrammatically the various couples which acted in a given case on the moving system of a (currentless) millicoulomb meter: K_{Fe} the couple due to the presence of iron in the not particularly pure coil, K_B the maximum

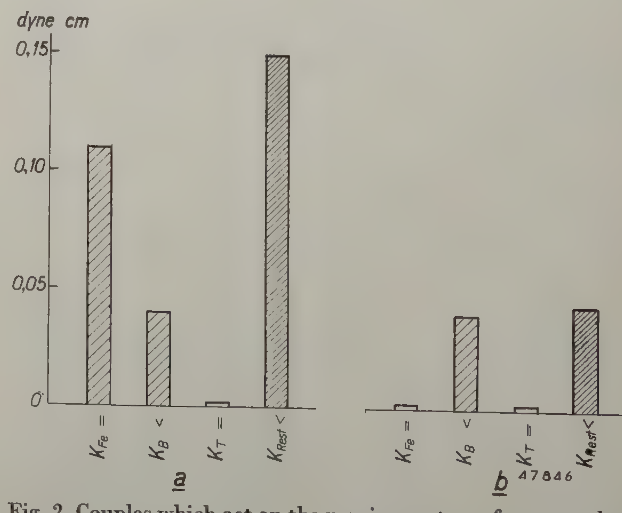


Fig. 2. Couples which act on the moving system of a currentless millicoulomb meter, *a*) for a moving system contaminated with iron. *b*) for one practically free of iron. K_{Fe} = iron couple, K_B maximum balancing couple, K_T = torsion couple, K_{rest} = resultant of K_{Fe}, K_B and K_T. (It is assumed that these three couples act in the same direction, *i.e.* in the most unfavourable case).

couple which remains due to unavoidable imperfections in the balancing, K_T the torsion couple of the current supply wires. Together they form the residual couple K_{min} which, if it is larger than the frictional couple, makes the system move. *Fig.2b* shows these couples for the same instrument with materials which have carefully been kept free of iron. It may be seen that the residual couple of max. 0.15 has been reduced to about max. 0.045 dyne cm.

Moving-coil meters with directional couple

Disturbed linear scale in galvanometers

The parasitic directional couple may be disturbing not only in the above-mentioned flux-meters and coulo-meters, but also in instruments with intended directional couple: it disturbs the linearity of the scale, owing to the total directional couple no longer being truly proportional to the deflection of the instrument. This phenomenon, it is true, is not noticeable in the usual sort of technical moving coil meters where the directional couple of the spiral springs is appreciably larger than the parasitic couple — even when no special attention is paid to the purity of the materials used for the coil; in the case of sensitive moving-coil galvanometers, however, with their so much weaker directional couple (torsion wire), deviations from linearity may occur, and it is just with these instruments that great value is often attached to a linear scale.

Varying zero position in meters with a logarithmic scale

There is still another unpleasant phenomenon which must also be ascribed to iron particles in the coil, namely a changing zero position. By this is meant the failure of the pointer of a measuring instrument to return exactly to zero, although it has previously been set accurately at zero; the difference from the true zero depends upon the magnitude of the deflection that the instrument has just recorded. If upon rotation of the coil not only the magnitude but also the direction of the field with respect to the coil changes, upon return to the neighbourhood of the zero position the ferromagnetic impurities will exhibit a remanent magnetization the direction of which depends upon the magnitude of the deflection. A directional couple thus remains which causes the so-called non-reproducible zero point. It is obvious that this phenomenon will also be stronger according as the field is less homogeneous.

Although, as a rule, a linear scale is desired in moving-coil meters, for special applications instruments are required with a non-linear scale, and in particular a logarithmic one, for instance meters calibrated in decibels as used for acoustic investigations and in communication technology [5]); further, also photographic exposure meters (with a photocell). In these cases the sensitivity of the meter should decrease as the deflection of the meter increases. This can be obtained by giving the magnetic circuit such dimensions that the field in which the coil moves changes according to a logarithmic law. In this case, therefore, the field is very inhomogeneous, resulting in a great variation of the zero point when the moving system contains ferromagnetic particles.

Relative determination of the iron content

From the above it follows that in the construction of the special kinds of moving-coil meters mentioned care must be taken that the materials of which the moving system is made are free of iron. This applies to the aluminium frame on which the coil is wound, and even for the small weights which balance it (*fig. 3*), although the latter are outside

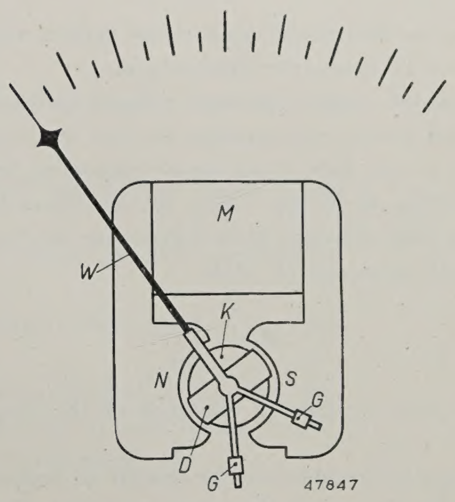


Fig. 3. Moving-coil meter. The permanent magnet M magnetizes the pole pieces N-S between which the moving coil D can rotate about the core K. The pointer W is attached to the coil. The movable counterweights G serve for balancing the moving system.

the air gap and thus situated in only a weak magnetic field. But the most important part, of course, is the copper wire used for the coil, which will be the main subject of our discourse in the following.

In order to be able to manufacture the necessary non-ferrous material, we first sought a simple method of quickly testing different samples for iron content. The choice fell upon a determination of the

[5]) For the reasons why a logarithmic scale is used here by preference, see Philips Techn. Rev. 2, 50, 1937.

remanence after magnetization in a field strong enough to reach saturation. Taken per unit weight of the material examined, the result is a measure of the magnetic behaviour of the substance. The remanent magnetic moment M_r is determined in a

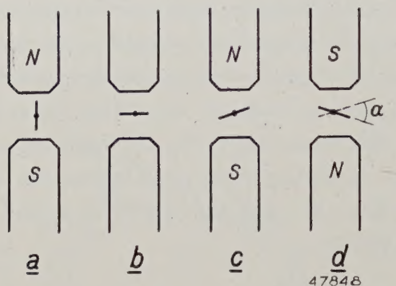


Fig. 4. Determination of the remanent magnetic moment of a copper specimen containing iron, for instance a small rod suspended on a torsion wire between the *N-S* poles of an electromagnet.

a) With a strong field the iron particles are magnetized.

b) After switching off the field the rod is turned 90°.

c) The electromagnet is weakly excited, causing a deflection of the rod.

d) After commutation the rod shows the opposite deflection. The angle through which it turns upon transition from *c*) to *d*) is measured with mirror and scale.

manner as illustrated in *fig. 4* and further explained in the text below the illustration.

From the angle α through which a test rod of the material under examination rotates upon commutation of the field, thus upon transition from the state of *fig. 4c* to that of *fig. 4d*, and from the prevailing field strength H, it follows for the remanent magnetic moment M_r that:

$$M_r = \frac{\alpha\tau}{2H},$$

where α is the torsion constant of the suspension wire.

If G_{Cu} is the mass of the sample of copper, then $m = M_r/G_{Cu}$ gives the above-mentioned measure of the ferromagnetic behaviour.

Measurements were first carried out with the apparatus of fig. 4 on technical electrolytical copper wire. The values found were very divergent, due for a large part to contaminations on the surface, as was very soon found. After removing a thin layer by etching in nitric acid the results lay between 2×10^{-5} and 4×10^{-5} Gauss cm³/gram and showed no change upon further etching (until the diameter of the wire had been reduced by one half). From this it may be concluded that the remaining iron particles are distributed homogeneously in the copper.

In the meantime it had been found that for the construction of meters with no directional couple the iron content of etched technical copper was a factor 10 to 20 too high. Consequently copper with a value of m not higher than about 10^{-6} was necessary.

Manufacture of non-ferrous copper wire

A suitable material for this purpose was found in so-called *OFHC* copper ("Oxygen-Free, High-Conductivity"), which was available as wire 1 mm thick, and after etching off a layer 10 μ thick, this had a homogeneously distributed iron content corresponding to $m = 1.5 \times 10^{-7}$. In this state of purity the material is diamagnetic, in contrast to technical copper. The measurement of the remanence, however, is still of value, because the diamagnetism shows no hysteresis.

This material thus reasonably satisfied the requirement as to purity, but it still had to be drawn out to a thickness of 25 μ needed for the construction of a certain meter. When this was done in the ordinary way, the iron content sometimes rose to $m = 10^{-5}$. It therefore proved necessary to draw the wire in a specially equipped wire drawing machine from which iron in every form had been eliminated as far as possible, which means, among other things, that:

the dies (diamonds) must be kept reserved exclusively for the drawing of non-ferrous copper wire; instead of steel only bronze tongs, forceps, etc. must be used;

no tap water, but only distilled water, must be used in the etching baths and for rinsing;

the atmosphere must be kept free of dust;

the wire must not be touched, not even with clean hands.

The importance of such measures will be evident from the following example.

In the above-mentioned apparatus a piece of copper gave a deflection of 12.5 cm. It was removed with steel forceps, rubbed slightly along the forceps and again hung in the apparatus. The deflection was then 19 cm. This corresponds to an increase in the magnetic moment of 3×10^{-7}, *i.e.* twice as much as 1 gram of the purest material contains! The fact that the iron content is indeed very small also follows from its determination by a chemical method, which leads to results of the order of 10^{-2}% for technical and 10^{-4}% for "non-ferrous" copper.

Practical results

The use of non-ferrous copper wire opens the possibility of considerably improving the quality of various kinds of moving-coil meters. Thus it is

possible in the case of meters with a non-linear scale to reduce the zero-point error, which may otherwise amount to one scale division, to an inappreciable value. Fig. 2 already showed the improvement in the residual couple of a millicoulomb meter. Before the use of non-ferrous material this couple caused the system to continue to move after with a velocity of about 1/20 scale division per second after the passage of current has ceased. When changing over to non-ferrous material, among other measures, this velocity was brought down to a maximum of 1/60 to 1/100 scale division per second in only a small part of the scale, while in the rest of the scale it was reduced to zero.

Issue No. 5 (of volume 1) of *Philips Research Reports* contains the following papers:

R22: A. A. Padmos: Checking the thermal expansion of glasses and metals by stress-optical tests.
R23: J. L. H. Jonker: The control of the current distribution in electron tubes.
R24: W. Elenbaas: Similarity of high-pressure discharges of the convection stabilized type.
R25: M. Gevers: The relation between; the power factor and the temperature coefficient of the dielectric constant of solid dielectrics IV.
R26: A. van der Ziel: Theory of grounded grid amplifier.

Readers interested in one of the above mentioned articles apply to the Administration of the Philips Physical Laboratory, Kastanjelaan, Eindhoven, Holland, where a limited number of copies are available for distribution. For a subscription to Philips Research Reports application should be made to the publishers of „Philips Technical Review".

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of the majority of these papers can be obtained on application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands. Those papers of which no reprints are available in sufficient number, are marked w;th an asterisk.

1693: J. M. Stevels: Chemische binding en reactiviteit van eenvoudige organische verbindingen (Chem. Weekblad **42**, 150-154, 1946) (Chemical bond and reactivity of simple organic compounds).

From experimental data the author shows that, at least for halogenated methane derivatives, the following properties of a C-X bond go together: stronger binding, larger dissociation energy, larger activation energy and collision number in the reaction with Na in the gas phase, smaller binding refraction, greater force constant of the C-X vibration. Extending to unsaturated compounds one may add stronger double bond character, smaller atomic distance.

1694: Balth. van der Pol. Merkwaardige eigenschappen van geheele getallen (Natuurkundige Voordrachten, Diligentia, band 23, den Haag, van Stockum, 1946).

(Remarkable properties of whole numbers).

This lecture treats some remarkable properties of whole numbers: prime numbers, Goldbach's conjecture, complex prime numbers, perfect numbers the number of prime numbers in a given interval, Skewes' number.

1695: P. J. Bouma. Colour equations (Physica 12, 189-194, 1946).

Two types of equation occur in colorimetry: algebraic equations and colour equations. The difference between these two kinds of equations is explained, and a special symbol (- - - - - -) is introduced in order to avoid the danger of confusion between the two types. This danger is illustrated by a worked example where the same problem is solved without and with the use of colour equations.

1696: J. F. H. Custers and J. C. Riemersma. The texture of straight-rolled and of cross-rolled molybdenum (Physica **12**, 195-208, 1946).

With the aid of pole figures the textures of straight-rolled and of cross-rolled molybdenum are determined. The pole figures thus obtained show, that earlier authors described these textures in too simple a way; they are at least twofold.

For example, after cross-rolling, there is found besides the so-called, (100) (110) texture (where the (100) plane is parallel to the rolling plane, and the (110) direction is parallel to the rolling direction) a second texture, which is rotary symmetrical around the normal to the rolling plane, and which has a (111) plane parallel to this plane.

The texture of straight-rolled molybdenum turns out to be in good agreement with the texture of straight-rolled iron, as determined by Krudjumow and Sachs; the texture of cross-rolled iron is not known.